# ELECTRON DRIFT/DIFFUSION MEASUREMENTS IN LIQUID ARGON

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## Outlines:

1. Introduction: Status
2. Experimental Setup
3. Minimum Drift Distance Results
4. Future Plan
5. Conclusions

# Charge response to ionization and the transport of charge

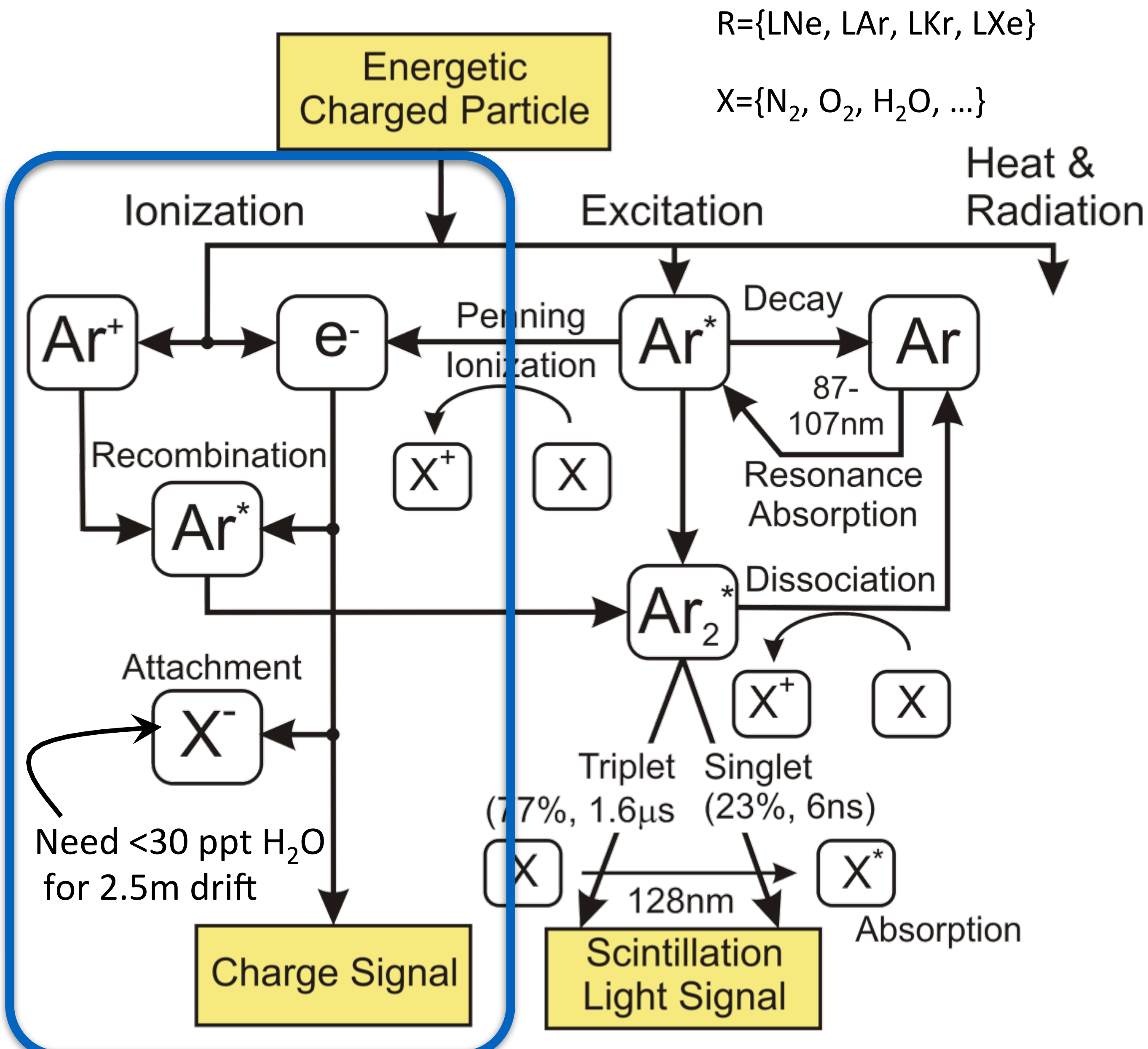
Observation of the motion of electrons in noble liquids is the primary means of event tracking and calorimetry in TPCs. All of the processes that contribute to the production and transport of electrons and ions are of interest for the optimization of TPCs.

1. Specific ionization as a function of specific energy loss and electric field especially at high energy loss (the recombination factor)
2. Diffusion of electrons (transverse & longitudinal) as a function of electric field
3. Attachment cross sections (rate constants) of electrons for all impurities
4. Mobility of positive ions (including the ions of impurities)
5. Optimization of transport properties with dopants, as has been done for gaseous detectors
6. Development of structures and conditions for gain in noble liquids
7. Optimization of photocathodes as a high brightness source of electrons in noble liquids
8. Analysis through Monte-Carlo simulations of optimization of signal processing and detector performance.
9. Henry's law constants for common impurities

# Properties of LAr – Response to ionizing radiation

Relevant fundamental properties of LAr:

- Electron Diffusion
- Light scattering and absorption
- Electron attachment




For E→∞
42,000 e/MeV
8980 e/mm for MIP

For E→0
51,300 ph/MeV
10,900 ph/mm for MIP

# Electron Diffusion in LAr

Very few results have been reported on the diffusion of electrons in LAr.

1. E. Shibamura, *et al.*, *Ratio of diffusion coefficient to mobility for electrons in liquid argon*, Phys. Rev. **A20** (1979) 2547.
   *T.Doke, Recent Deveoplment of Liquid Xenon Detectors* , NIM 196(1982)87-96(***E > 1.5 kV/cm***)
2. S.E. Derenzo, LBL Physics Note No. 786 (1974) unpublished . ***(E= 1.4 & 2.7 kV/cm)***

3. S.E. Derenzo *et al.*, *Test of a liquid argon ion chamber with a 20mm RMS resolution*, **NIM** 122 (1974) 319 . ***(E=2.7kV/cm )***

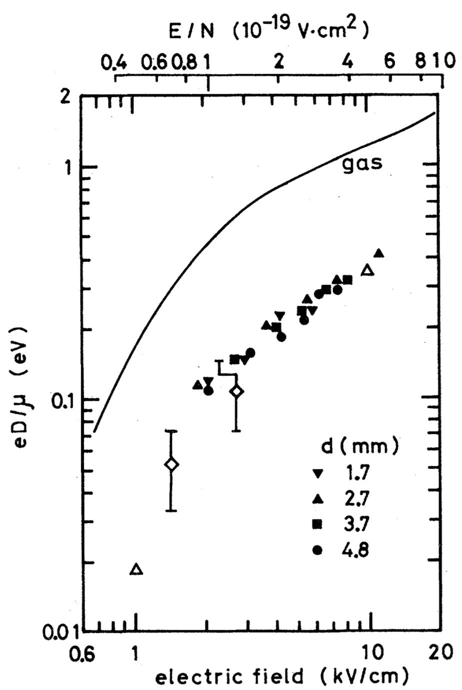
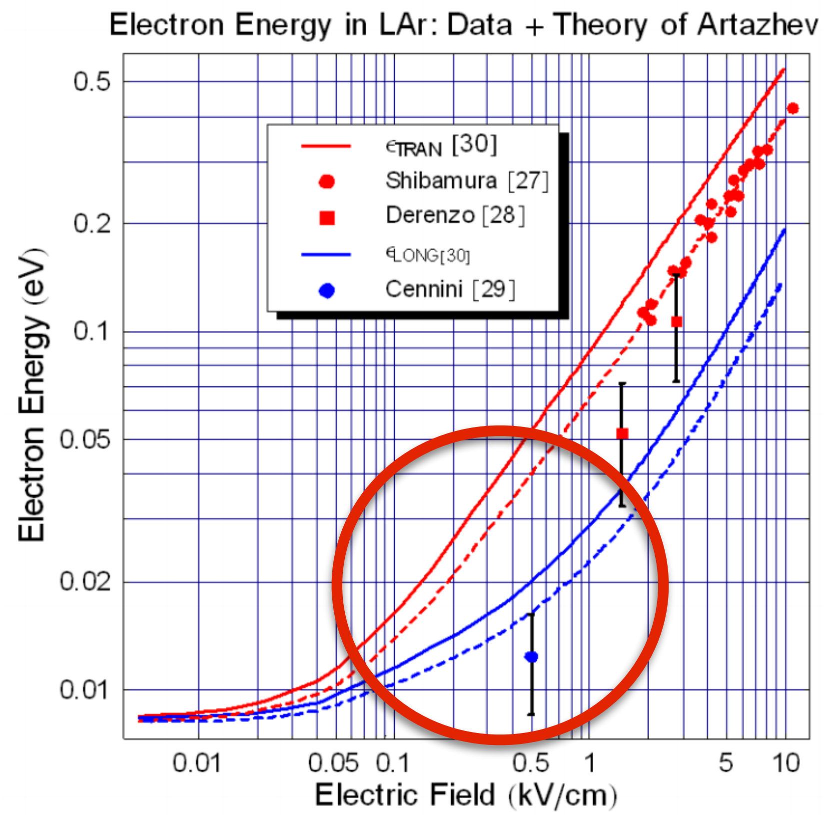



FIG. 7. Field dependence of the ratio $eD/\mu$ in liquid argon. The symbols ▲, ▼, ■, and ● represent the present results. Points ◇ and △ are the results according to Derenzo (Ref. 9) and Lekner (Ref. 7), respectively. Solid curve shows the results for gaseous argon. In the upper horizontal scale, $N$ is the atomic density in liquid argon ($2.1\times10^{22}$ cm$^{-3}$).

$$\varepsilon_e \equiv \frac{eD_e}{\mu_e}; \quad \sigma = \sqrt{\frac{2\varepsilon_e \Delta z}{E_D}}$$




$D_{Derenzo}$~15cm$^2$/s

$D_{Shibumura}$~15.5cm$^2$/s

No direct measurement on transverse diffusion under ***E~0.5kV/cm***

Only results on longitudinal measurement reported by ICARUS groups may contain large error.

# Electron Diffusion in Strong Electric Fields

## Diffusion of electrons in strong electric fields is not isotropic.

mean free path is independent of velocity:

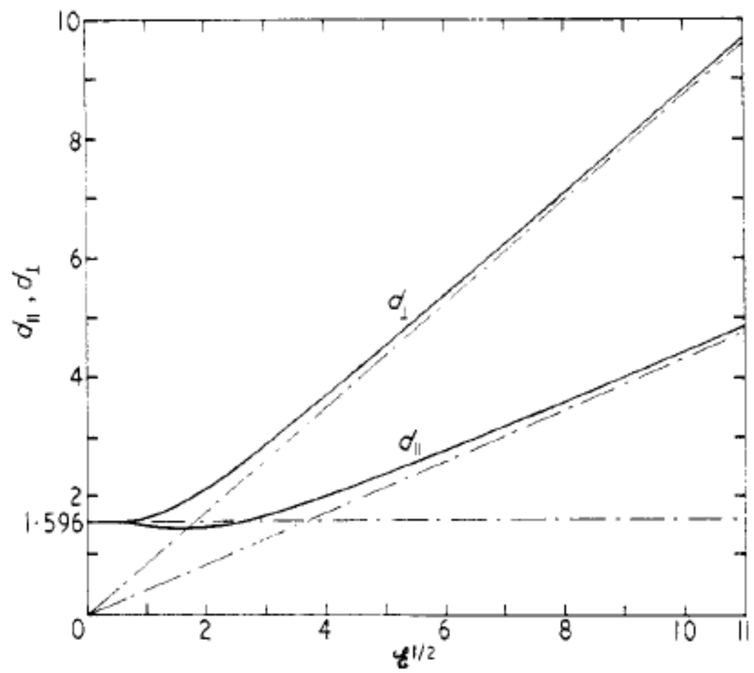



Figure 1. The dimensionless diffusion coefficients $d_\parallel = ND_\parallel \sigma_M (kT/m)^{-1/2}$ and $d_\perp = ND_\perp \sigma_M (kT/m)^{-1/2}$ as functions of the dimensionless field parameter $\mathscr{E} = (E/N)(e/kT\sigma_M)(M/m)^{1/2}$. Asymptotic values for large and small $\mathscr{E}$ are shown as broken lines.

collision rate proportional to a power of velocity:

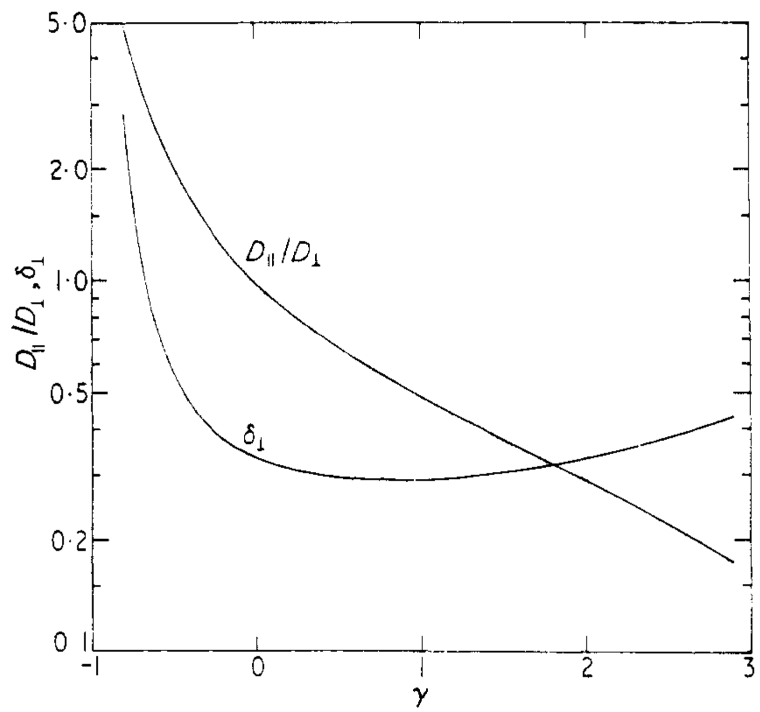



Figure 2. The dimensionless diffusion coefficient $\delta_\perp$ (equation (59)) and the ratio $D_\parallel/D_\perp$ of the longitudinal to the lateral diffusion coefficient for the case of a strong electric field and a collision frequency $\nu_M \propto v^\gamma$, as functions of $\gamma$.

H.R. Skullerud, *Longitudinal diffusion of electrons in electrostatic fields in gases*, J. Phys. B**2** (1969) 696.
J.H. Parker and J.J. Lowke, *Theory of electron diffusion parallel to electric fields. I. Theory*, Phys. Rev. **181** (1969) 290.

By solving Boltzmann transportation equation, theory predicts the longitudinal diffusion and transverse diffusion coefficient are different. Transverse diffusion is more significant than longitudinal diffusion.

The distribution of electrons in the originally point-like cluster is:

$$N(t) = \frac{n_0}{e(4\pi D_T t)(4\pi D_L t)^{1/2}} \exp\left[-\frac{(x^2+y^2)}{4D_T t}\right] \exp\left[-\frac{(z+v_d t)^2}{4D_L t}\right]$$

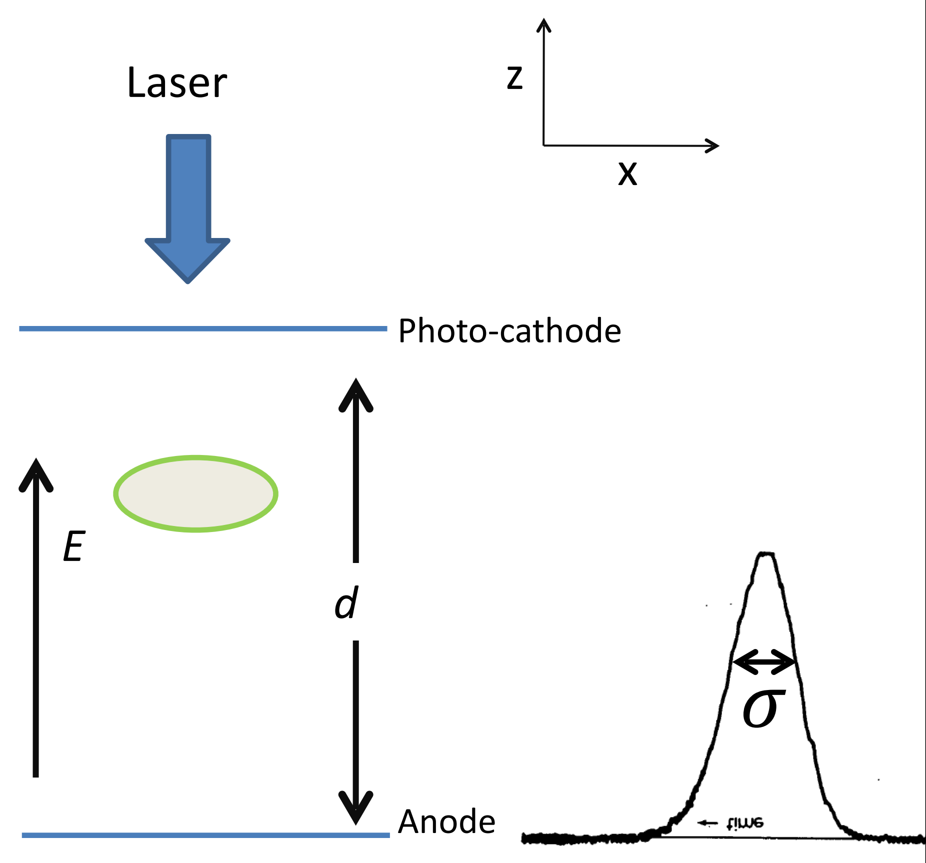
# Drift and Longitudinal Diffusion Measurement

Drift velocity is measured by a time-of-flight method.

$$v = \frac{d}{t_m}$$

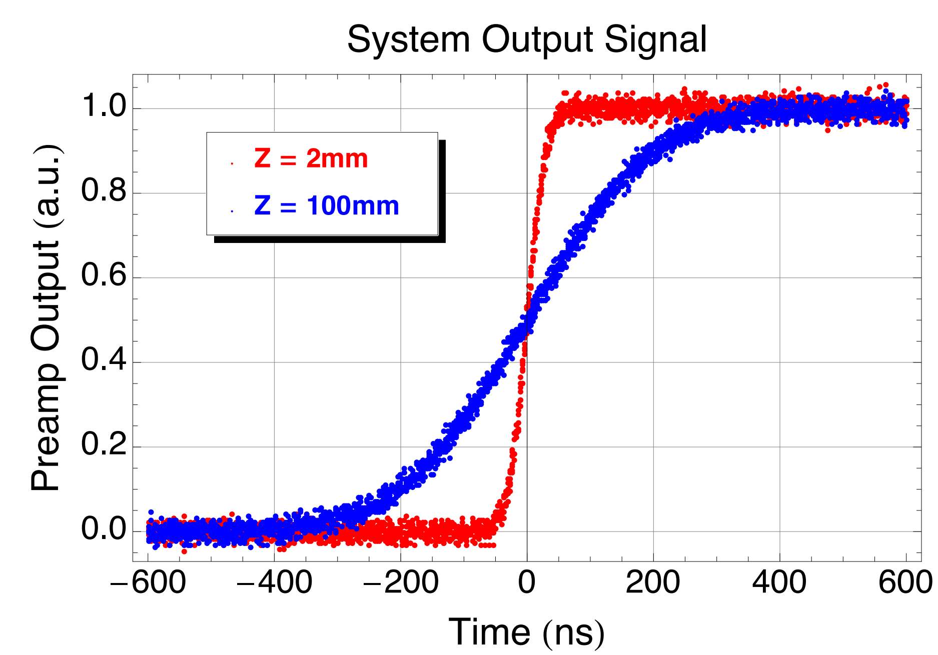
The distribution of anode current j(d,t) generated by a delta pulse of $n_0$ electrons emitted from the cathode at t=0

$$j(d,t) = \frac{n_0}{(4\pi D_L t)^{1/2}} \frac{d}{t} \exp\left[ -\frac{(z+v_d t)^2}{4\pi D_L t} \right]$$



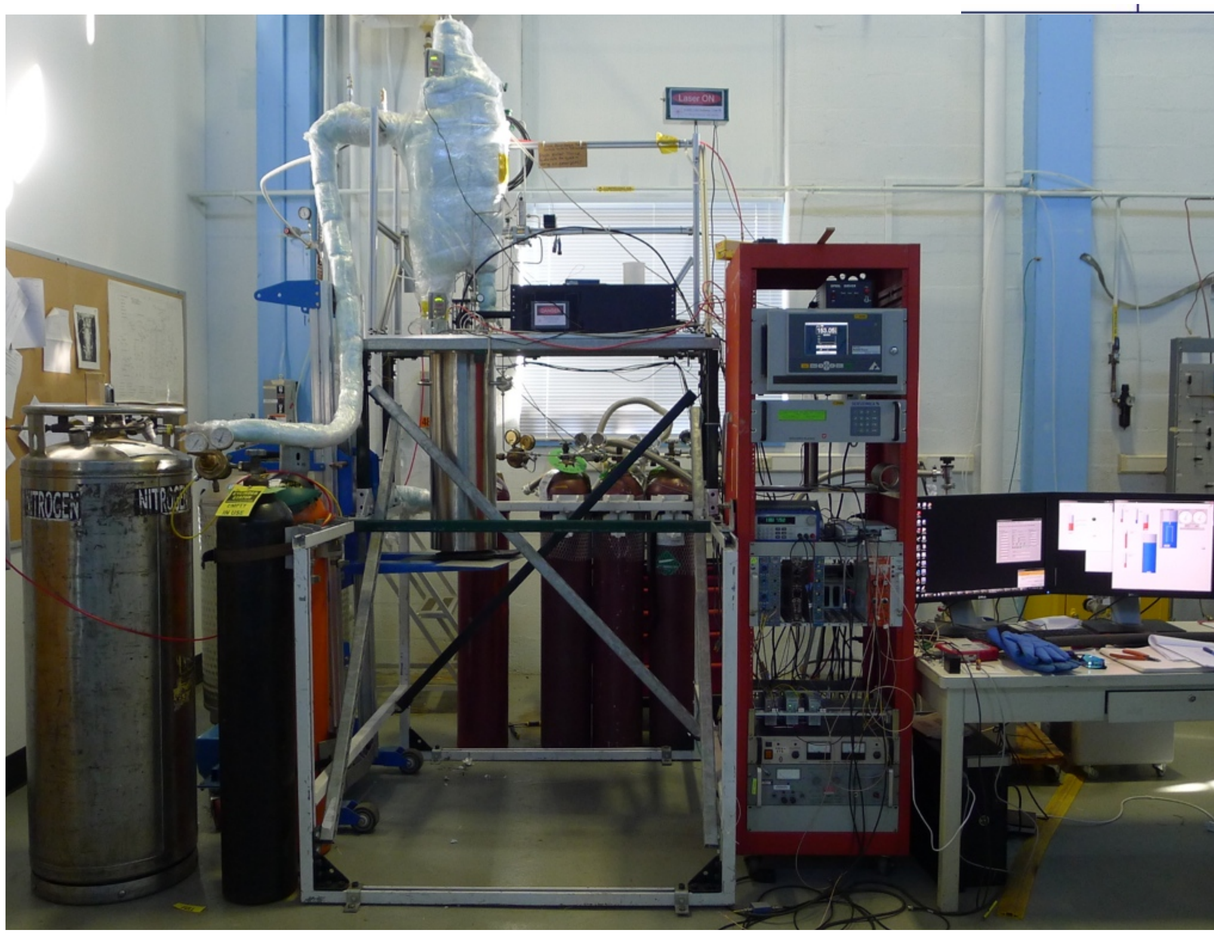

Longitudinal Diffusion is indicated by the width of the pulse from the anode, i.e. the rise time of the charge signal on the preamp.

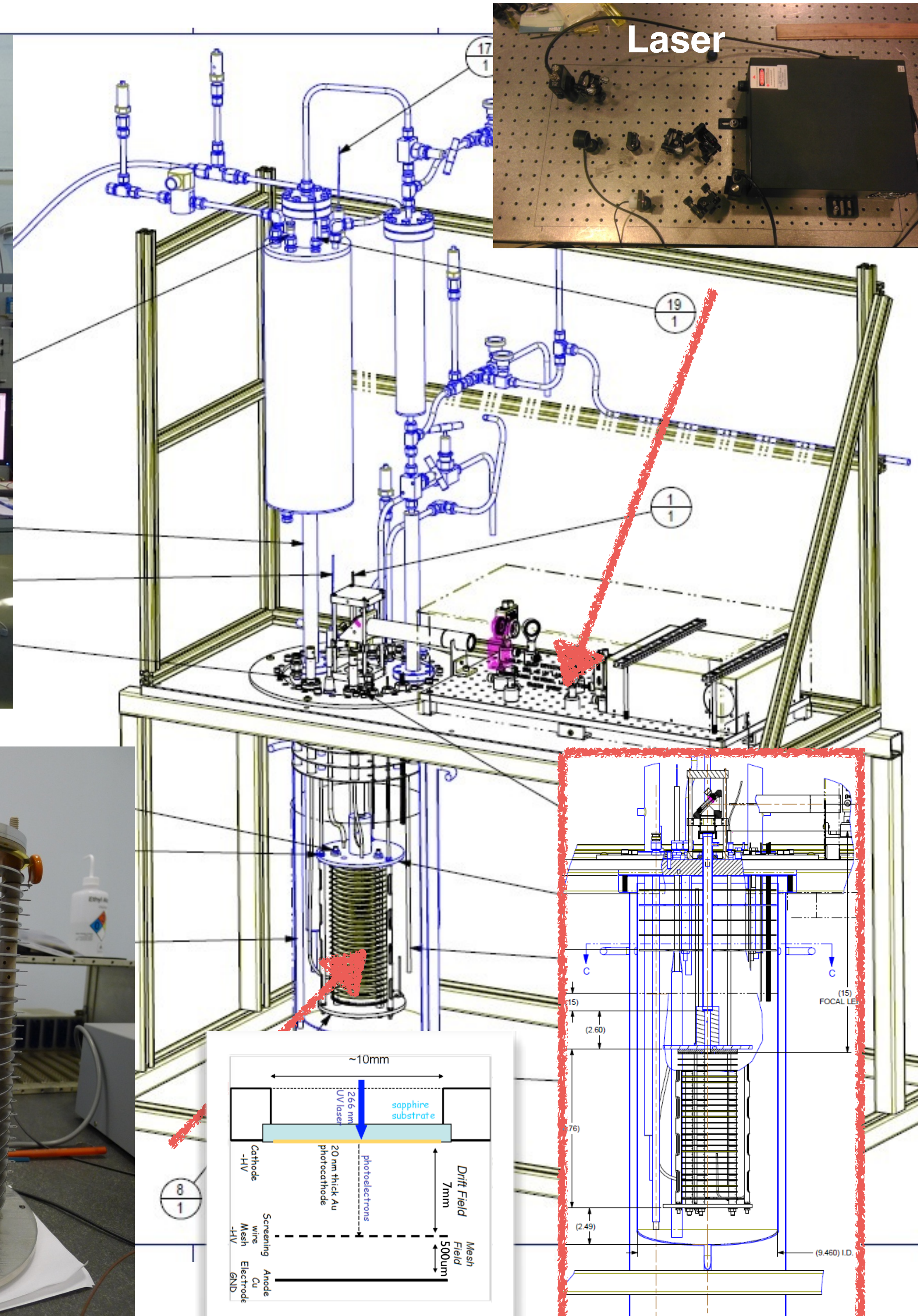
$$erf(t,\sigma) = \frac{1}{\sqrt{2\pi}\sigma} \int_0^t Exp\left( -\frac{x^2}{2\sigma^2} \right) dx$$

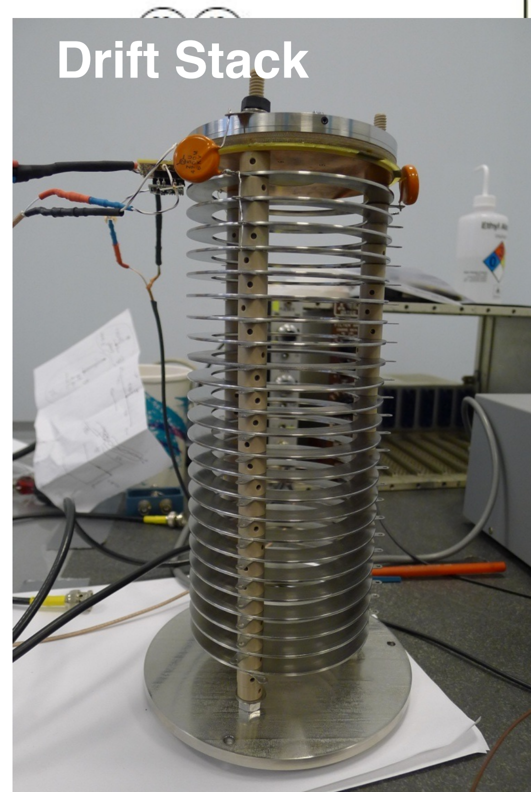


# Experiment Setup

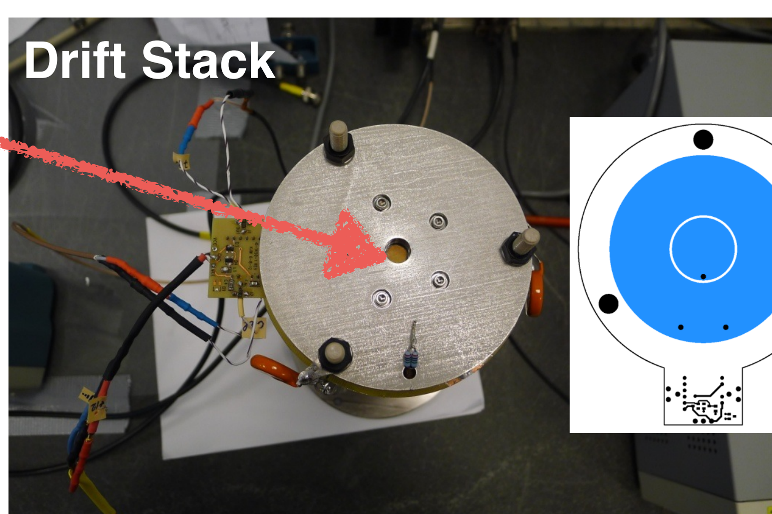
1. The Experiment Setup is located at High Bay area.





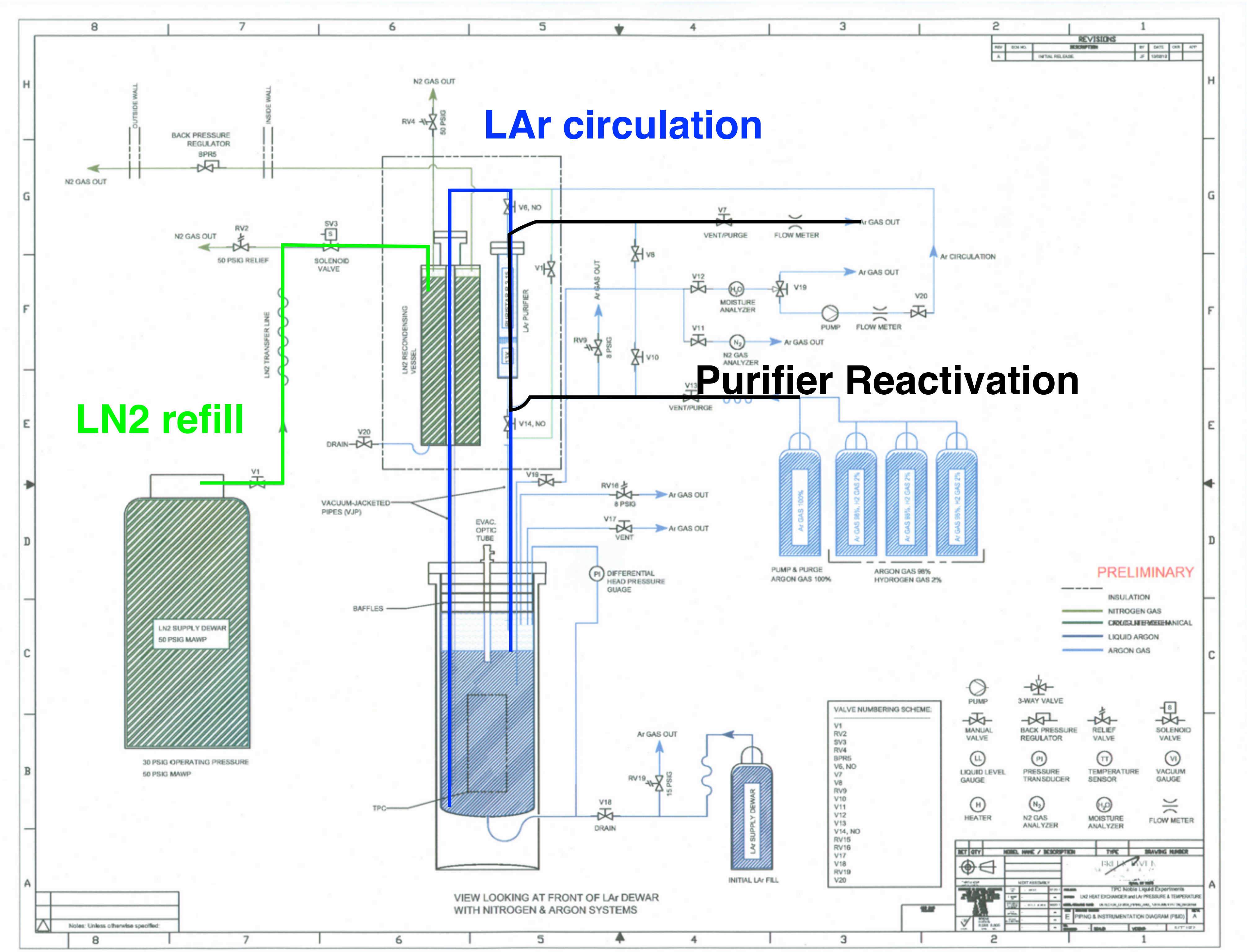




**PhotoCahtode**



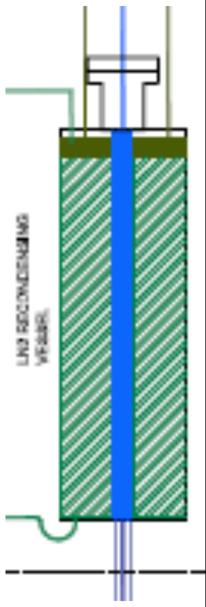
# Cryogenic Operation

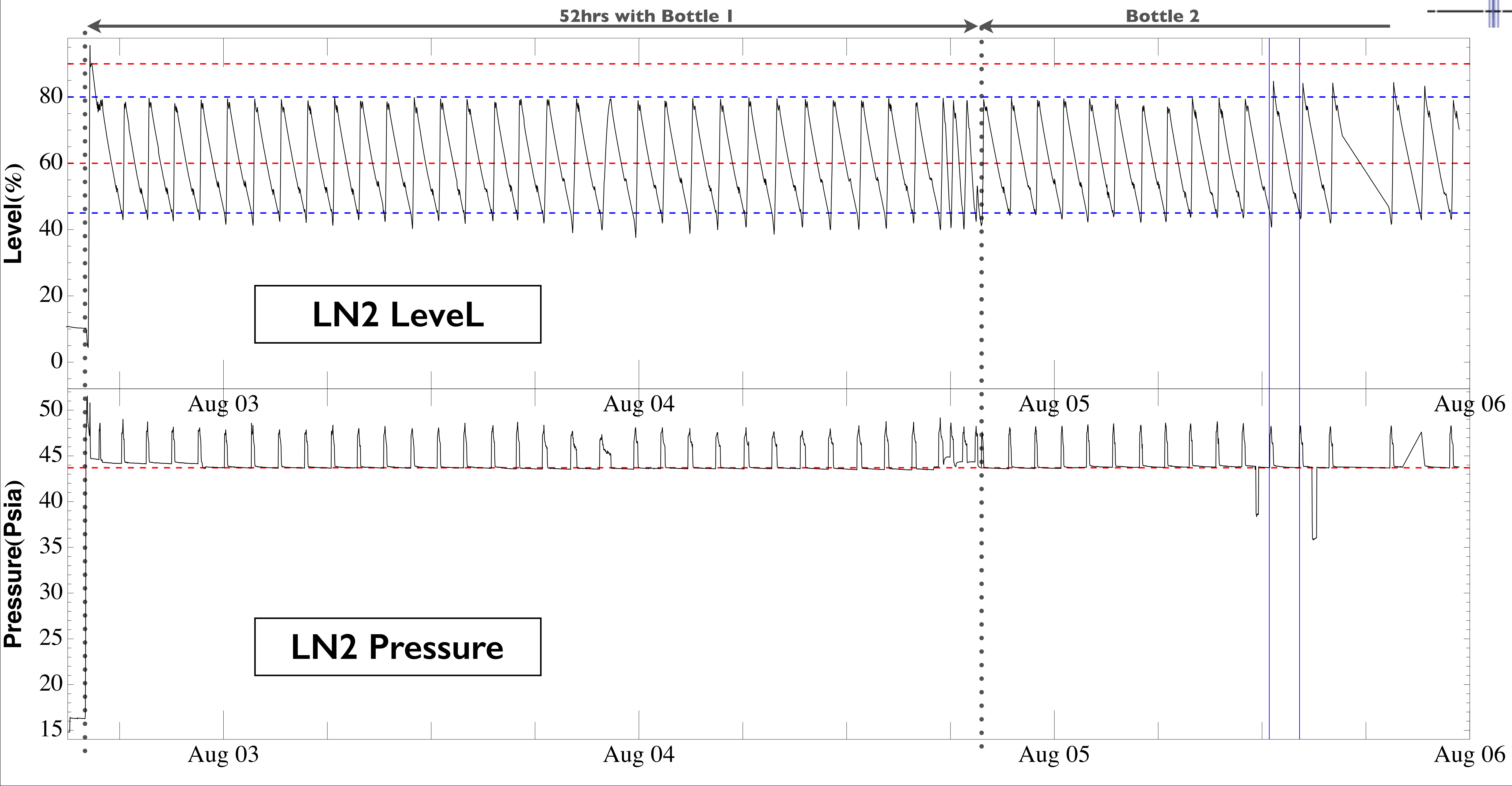
1. The Operation includes 3 major processes.



# Cryogenic System Operation: LN2 Filling

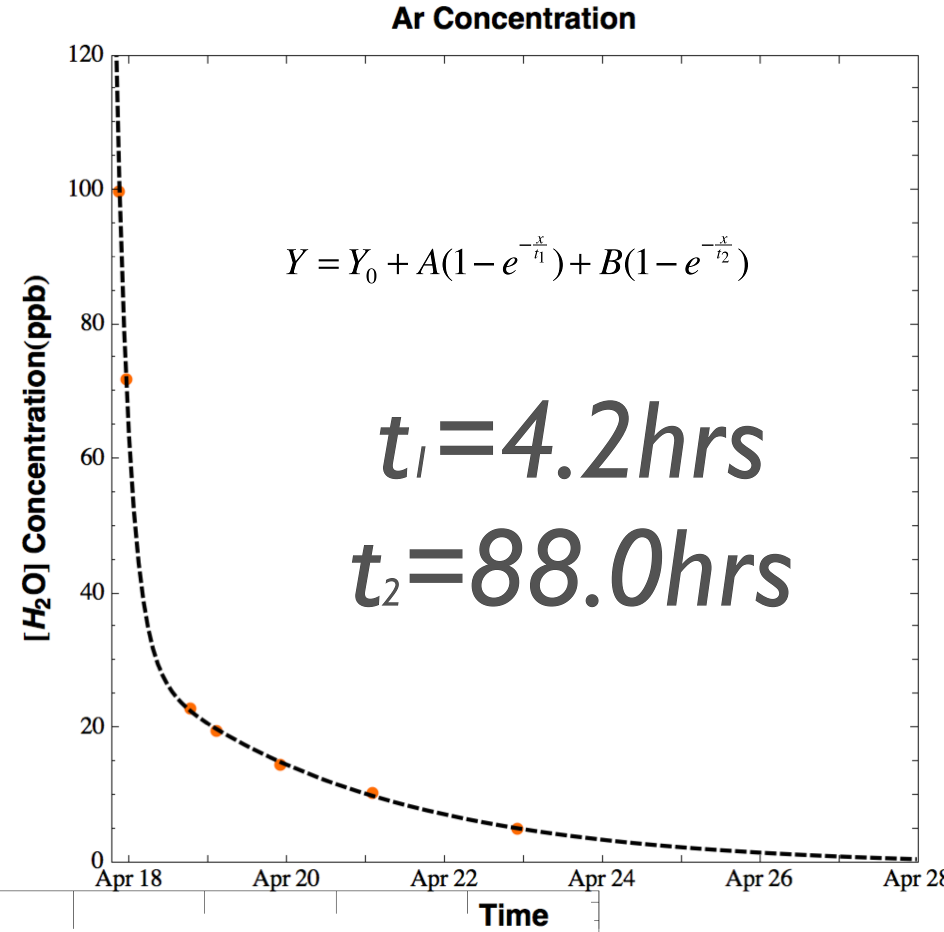
1. The cooling is provided by pressured LN2 filling into the recondenser.
2. A batch fill approach is used. Filling circle is ~every1.5hr.
3. The intrinsic heat load of the system is ~50W. Heater can add up to another 150W.

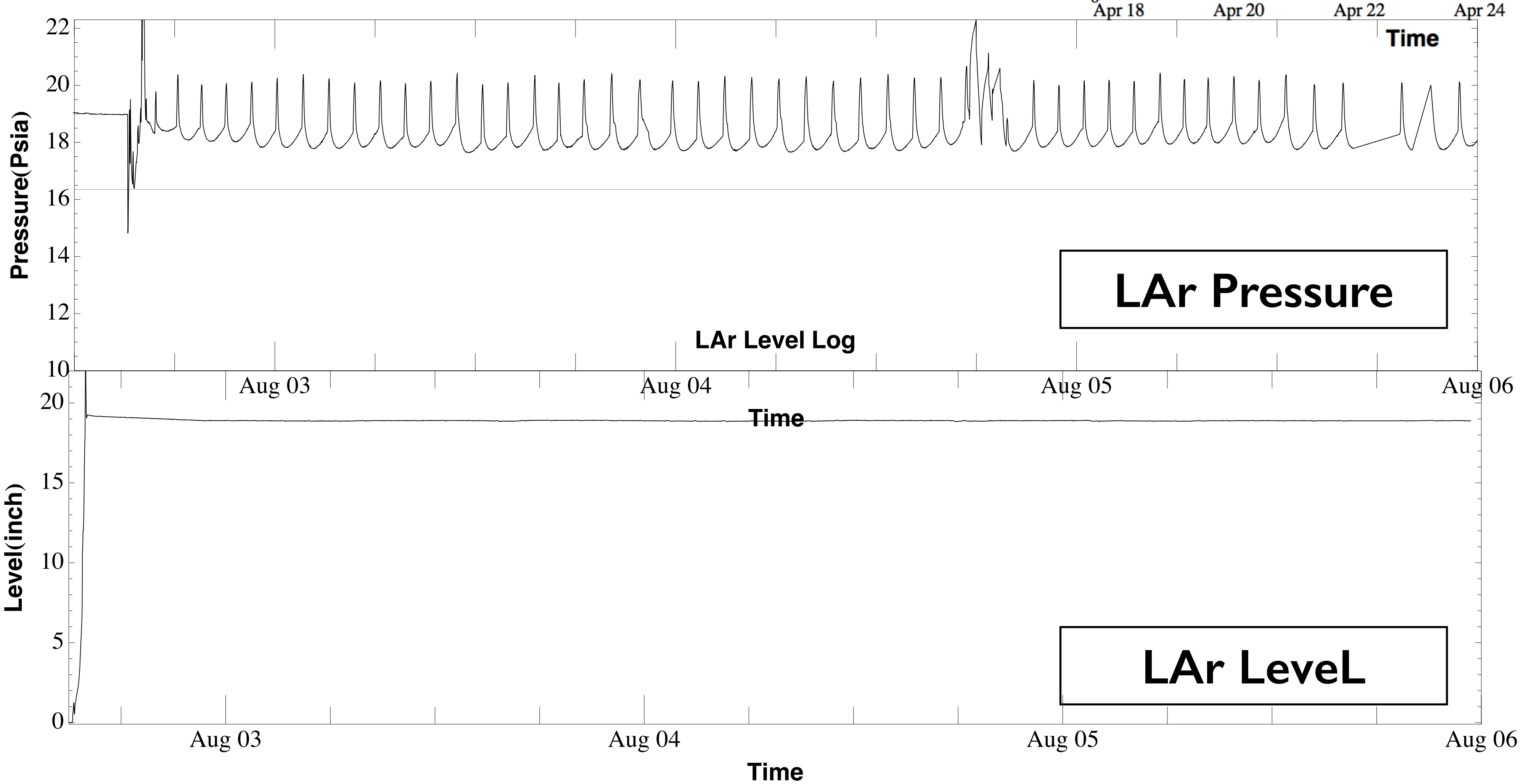


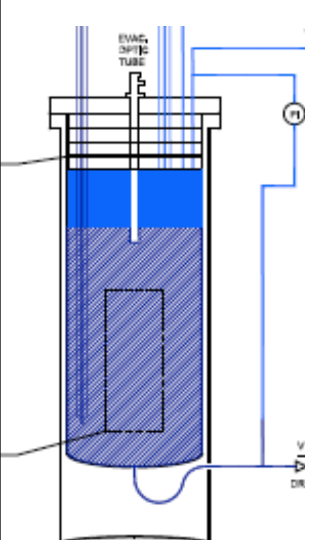


# Cryogenic System Operation: LAr

1. [H2O] ~60ppb, [N2]~8-9ppm sampling from liquid right after initial fill. No moisture data has been taken after that in order to maintain LAr level.
2. Estimation of [H2O] based by the LAr cleaning curve taken at the engineering run, assuming the purifier with the same cleaning capability. [H2O] < 1ppb after 7 days.

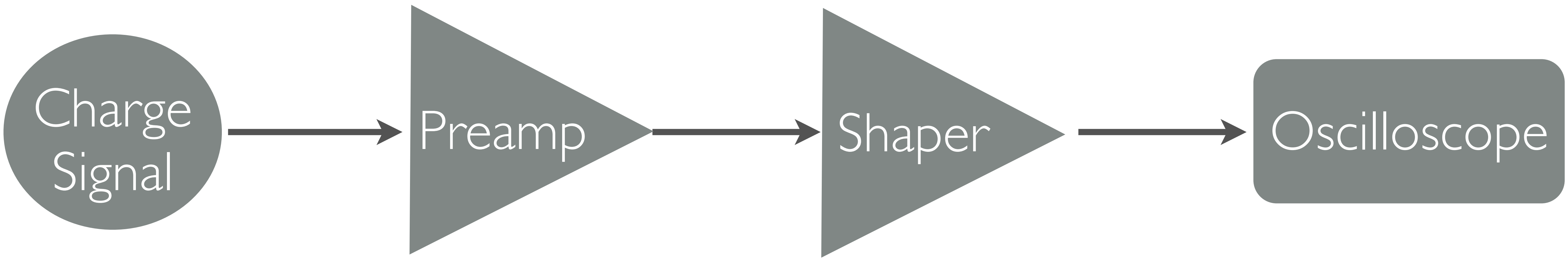


# System Modeling

1. In order to simulate the charge signal analysis the experimental data. A model is developed including all the components of the system.



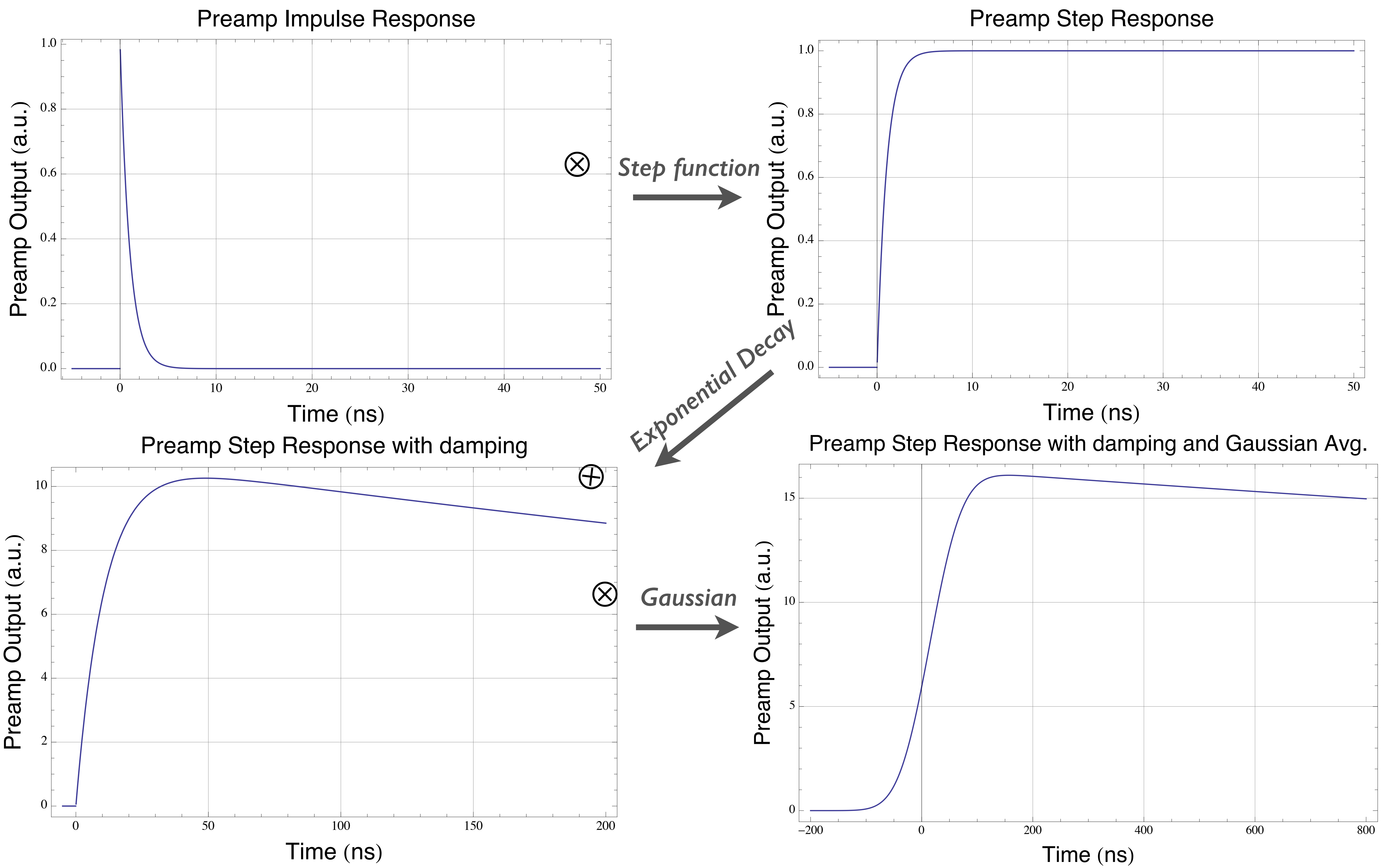

2. The model is basically a series of convolutions processes by treating each individual module as a filter:

$$V_{out}(t) = V_{electron}(t) \otimes H_{preamp}(t) \otimes H_{shaper}(t)$$

H(t) is the transfer function in time domain

# System Modeling: Preamp Modeling

1. The preamplifier response is also separated into several convolutions processes.
2. The model agrees with the preamp response to the pulser input data.



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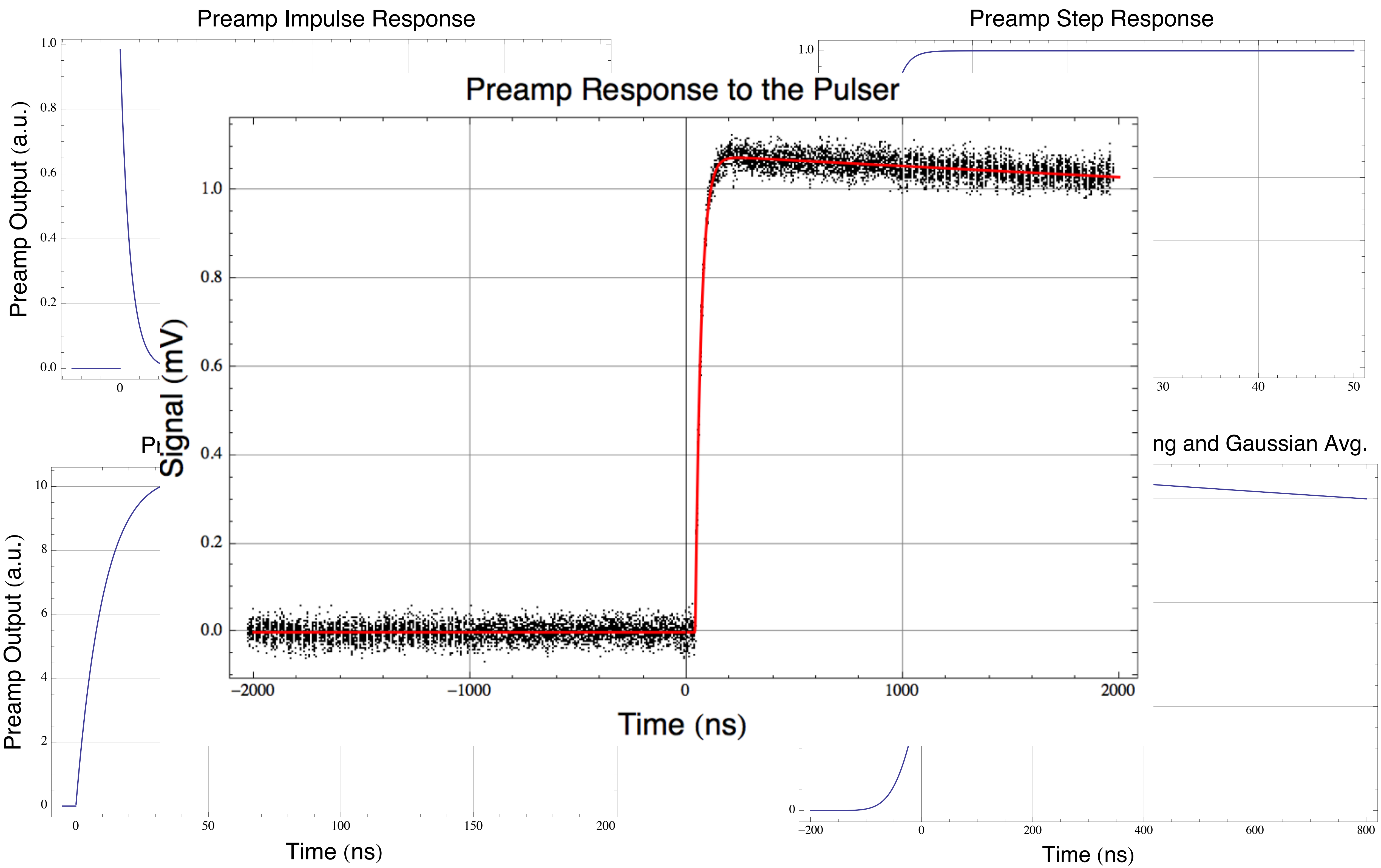

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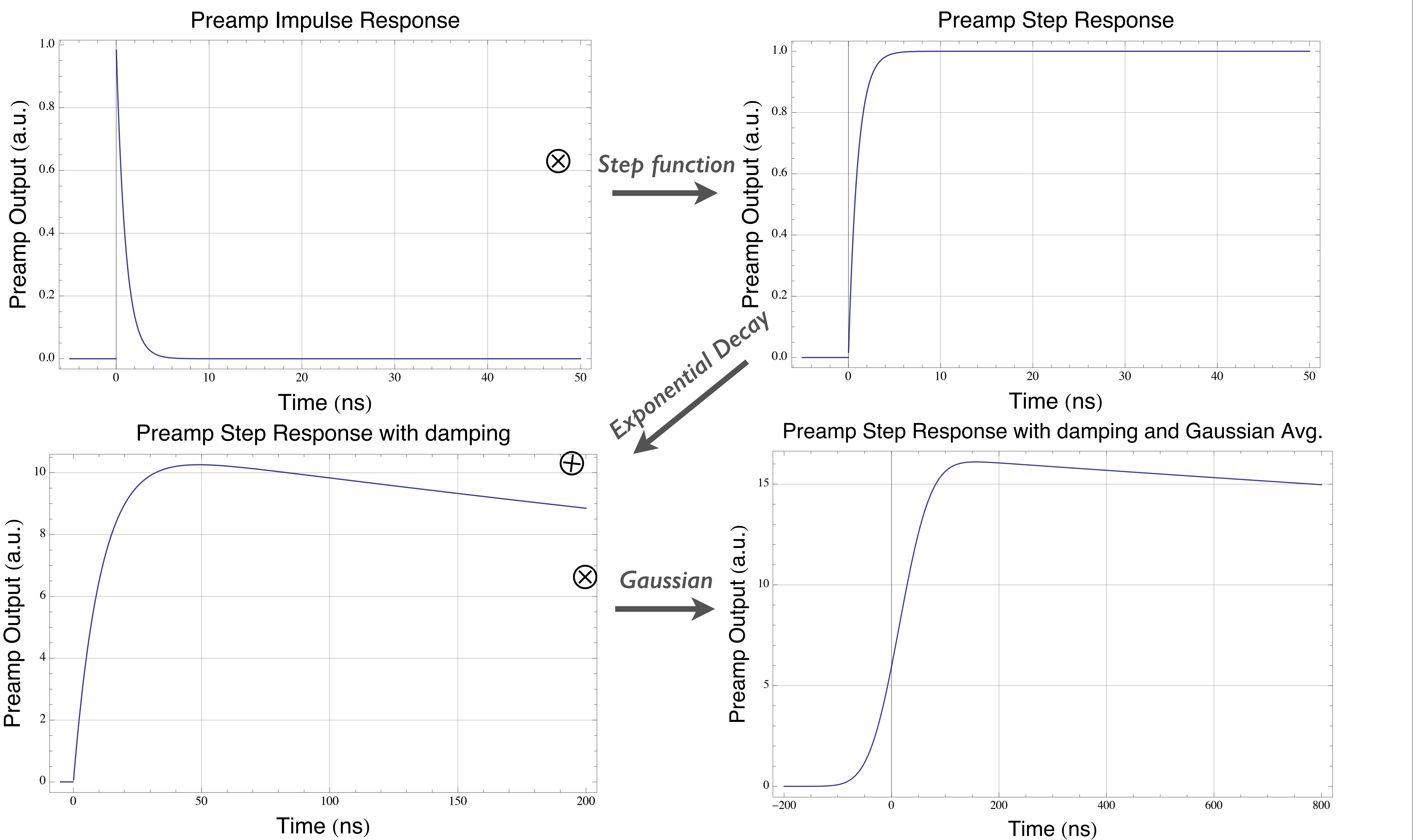


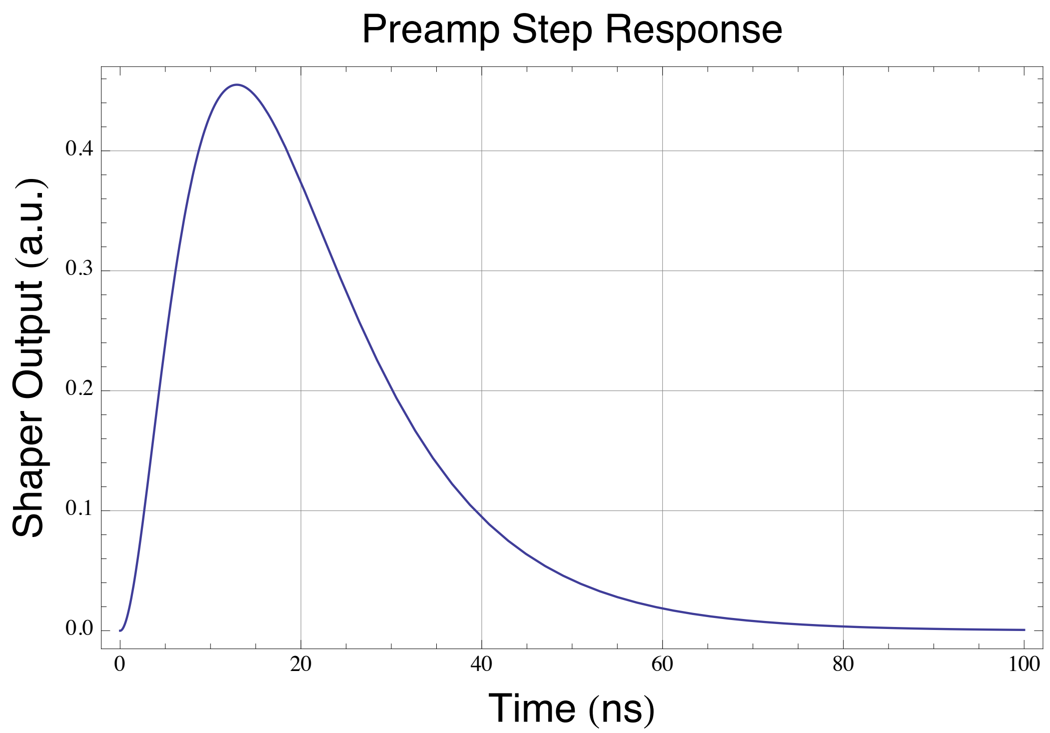
# System Modeling: Shaping Amplifier Modeling

1. The shaping amplifier is simulated as a CR-RC$^n$ filter with a transfer function as

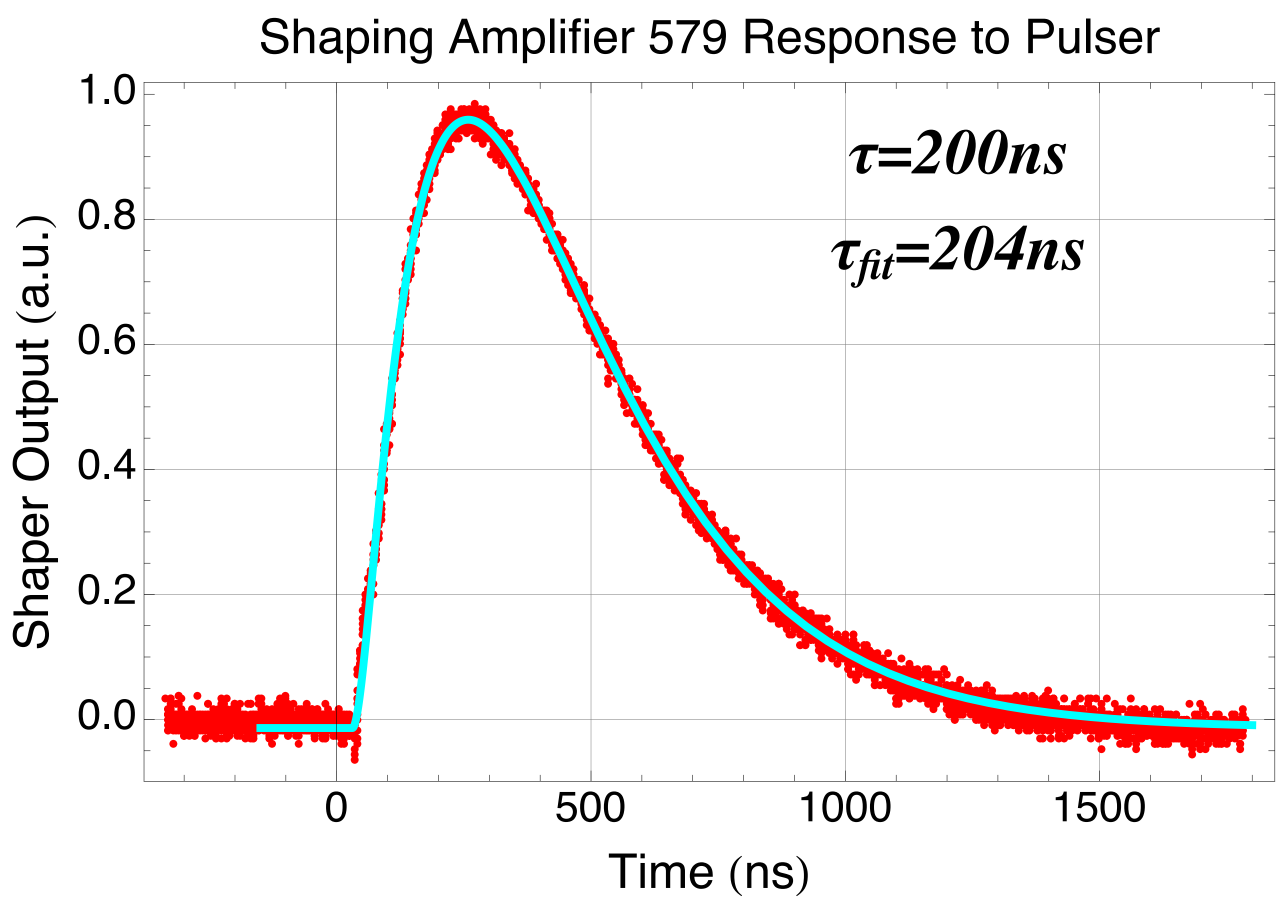
$$H(s)=\left(\frac{s\tau}{1+s\tau}\right)\left(\frac{1}{1+s\tau}\right)^n$$

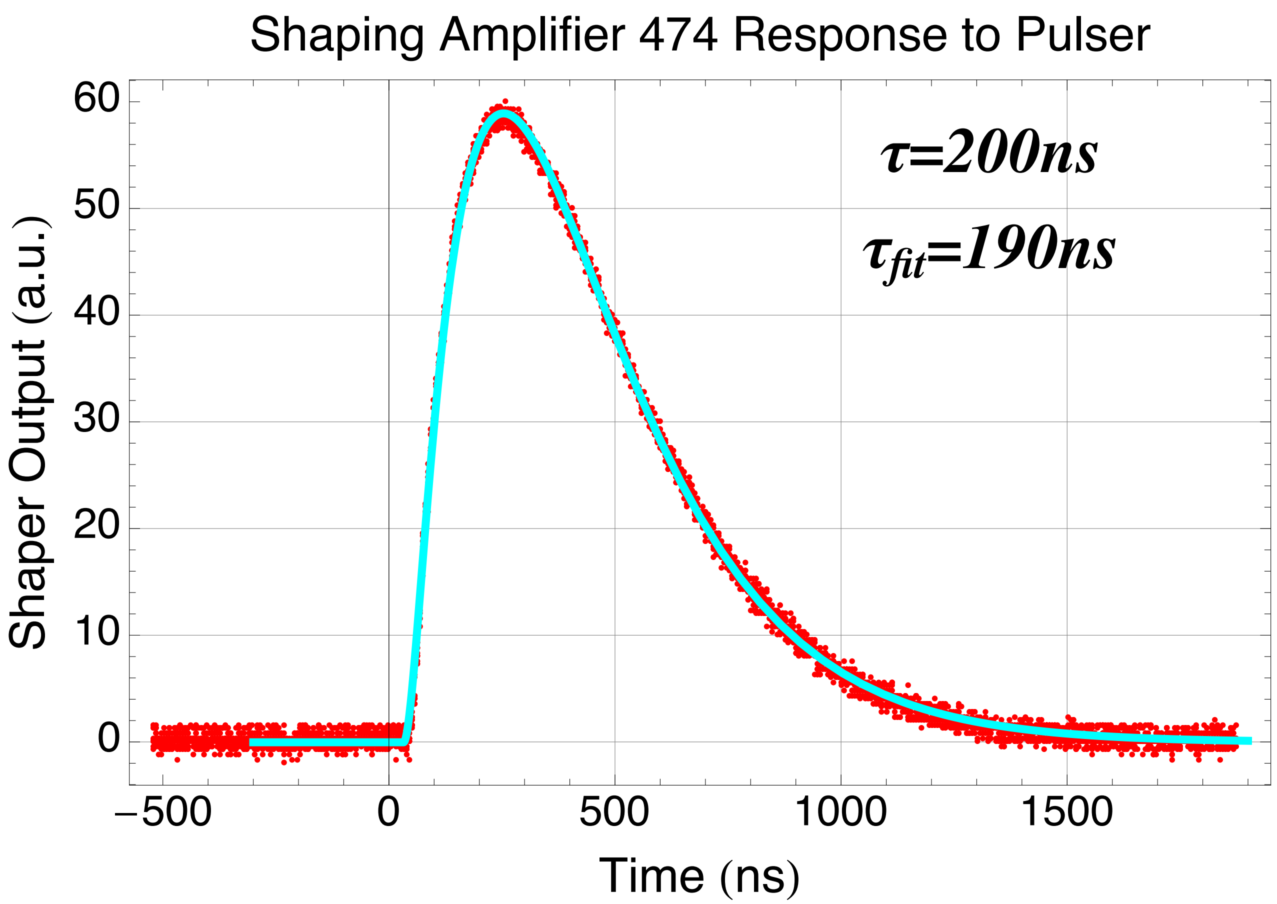
Its impulse response is $L^{-1}\{H(s)\}$

Step response is $H(t)=\int_0^\infty L^{-1}\{H(s)\}dt$



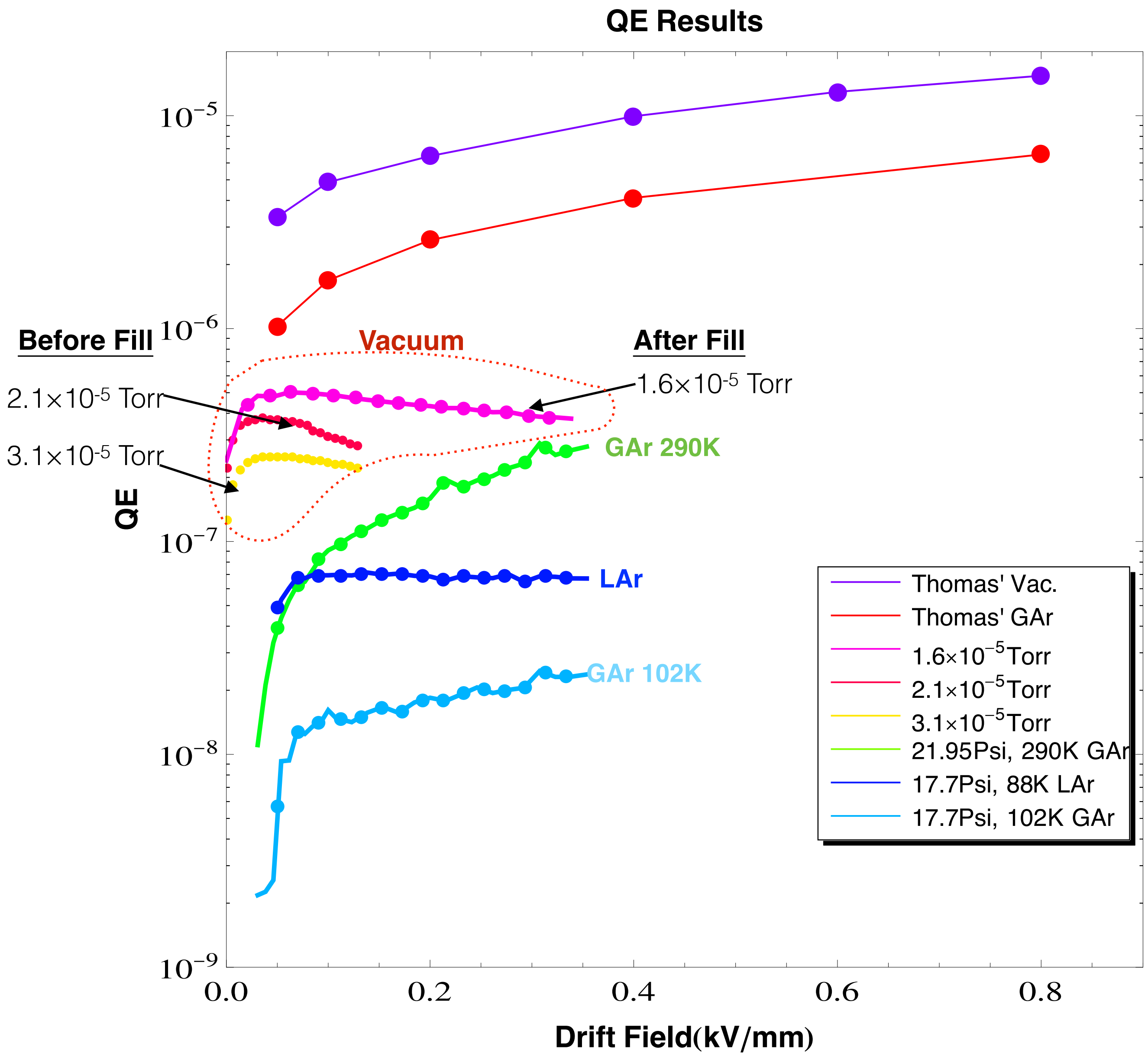

2. The pulser signal is applied into two different shaping amplifiers and the model with single stage CR-RC shaping agrees with the data.



# QE Comparison

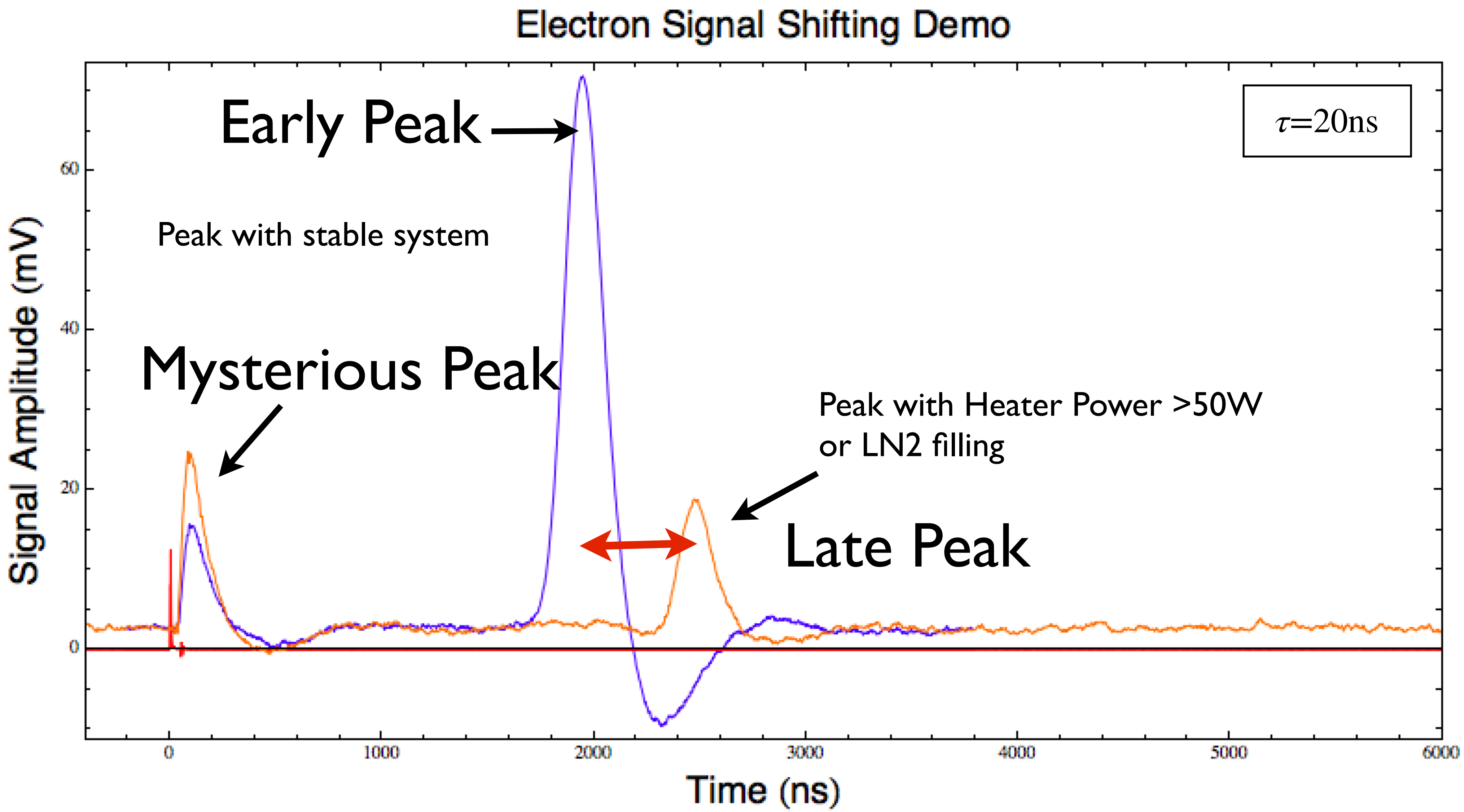
1. The QE was measured in Vacuum and GAr to compare the performance of the photocathode.
2. The QE of the photocathode does not change much after a cold/warm circle.
3. The upper surface of the sapphire substrate is very dirty.

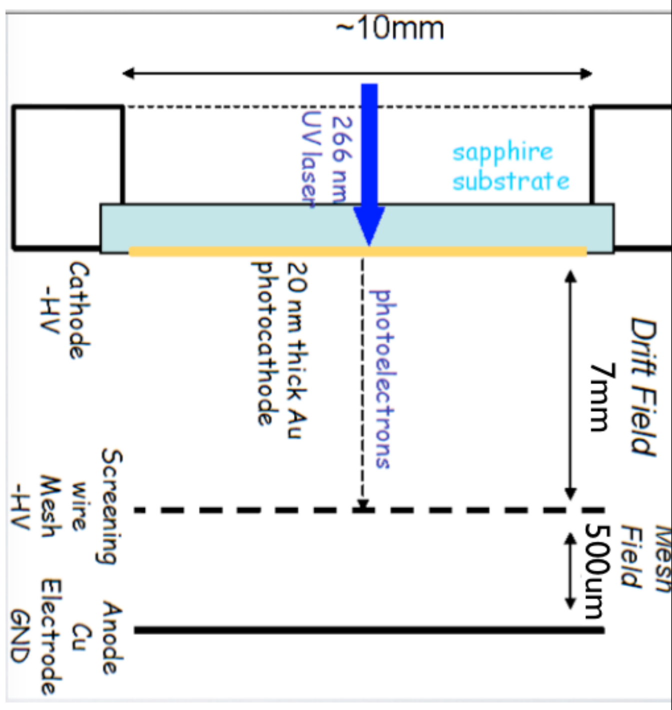



**photocathode Upper surface**


# Charge Signal

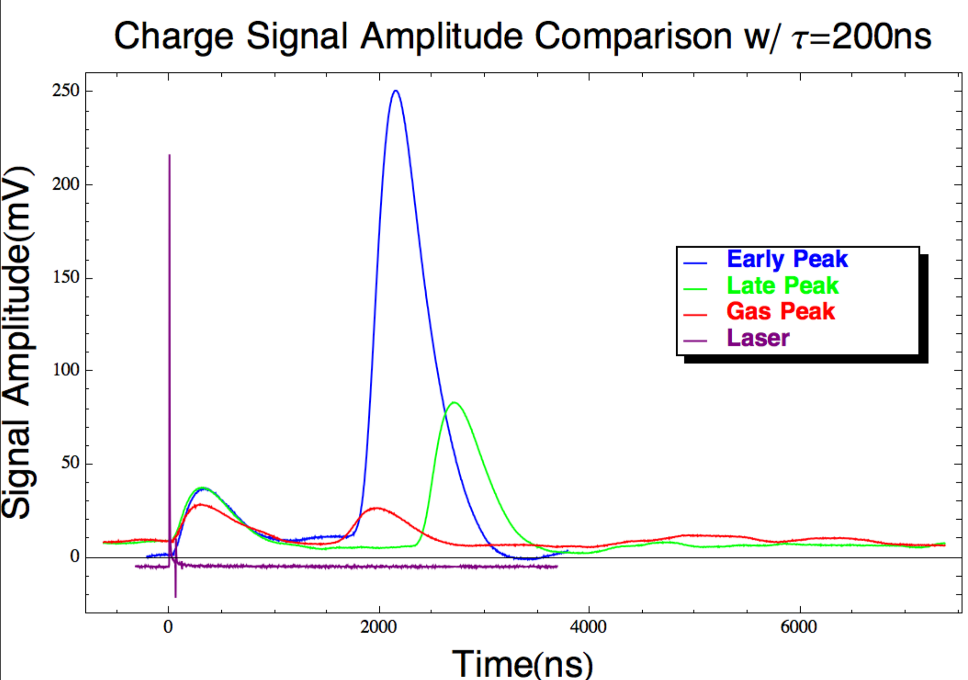
1. The charge signal peak shifting behavior has been observed during LN2 filling.
2. Turning on the heater immersed in the LAr has the same peak shifting effect.
3. The signal shifting is repeatable.
4. For convenience, I name the two peaks by Early/Late.

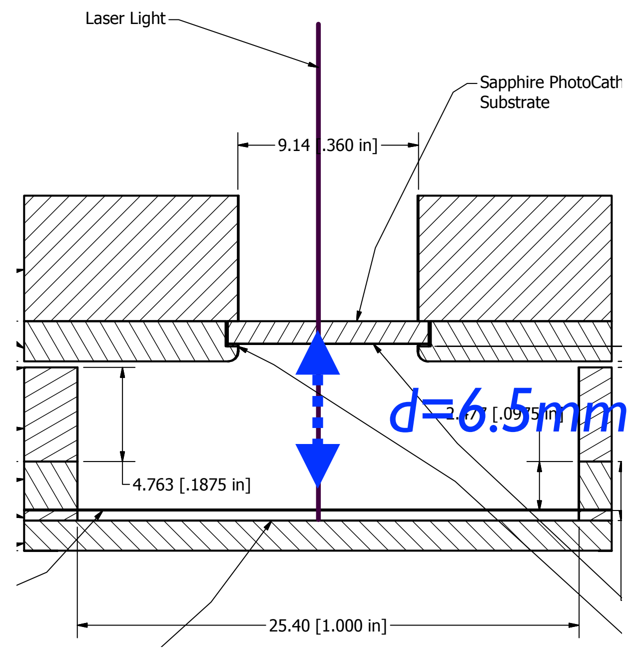


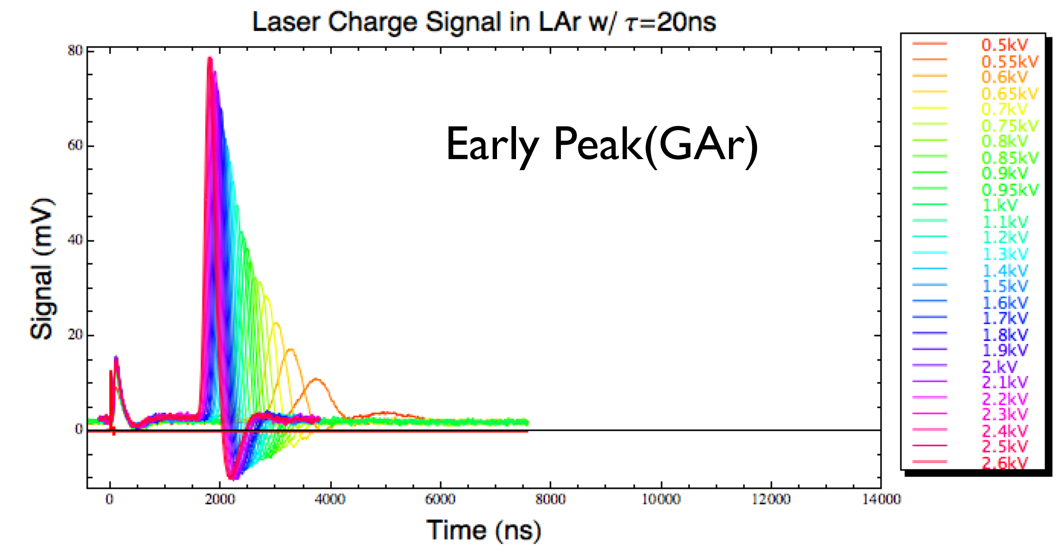



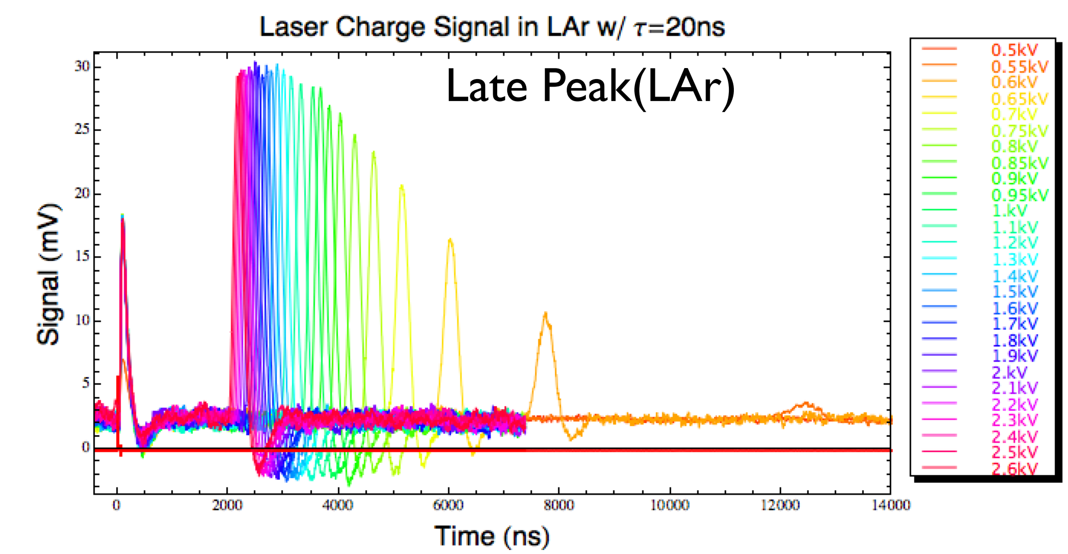
# Charge Signal

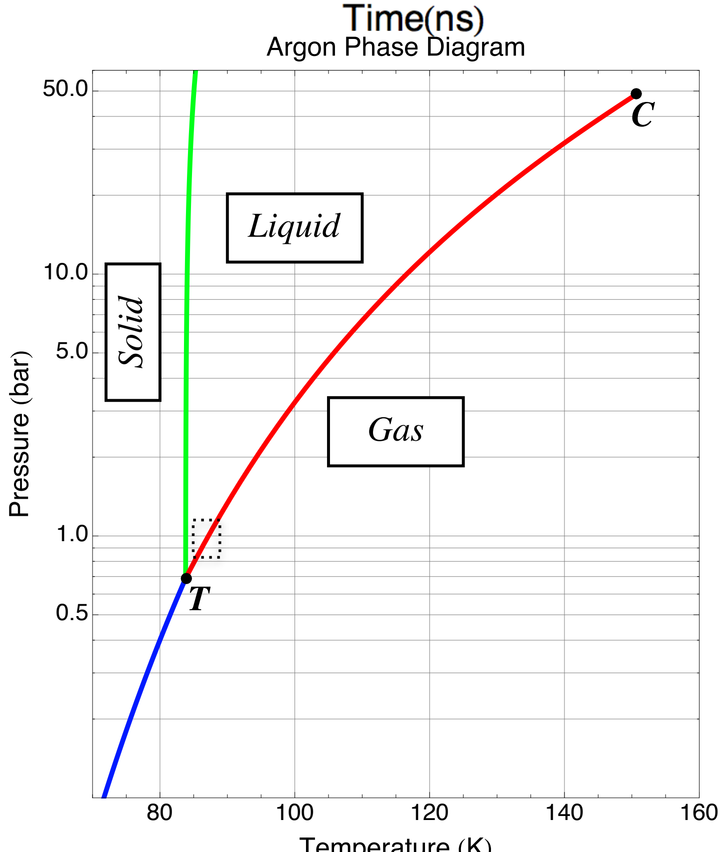
1. The charge signal is measured with minimum drift distance 6.5mm in this round.
2. Two sets of signal were observed in LAr.
3. It is caused by different Ar phase.

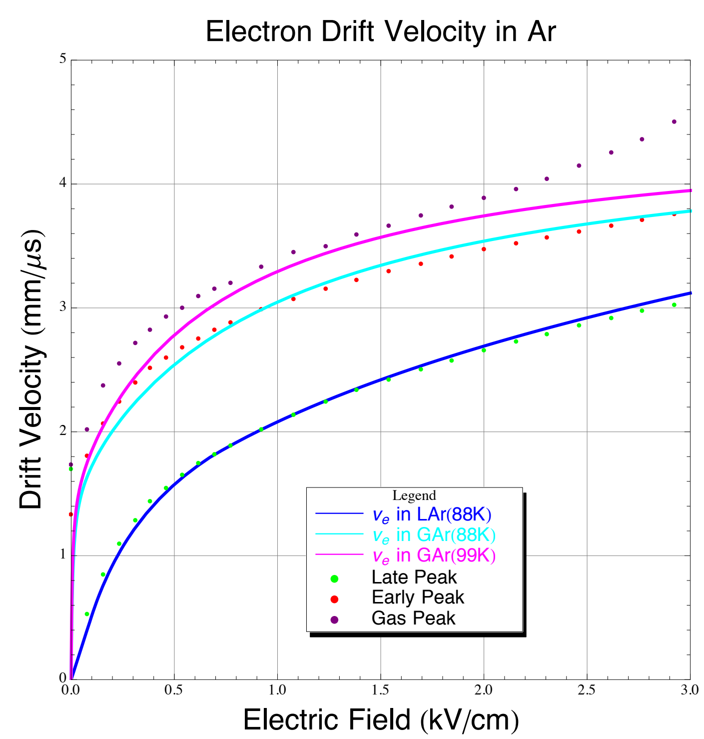


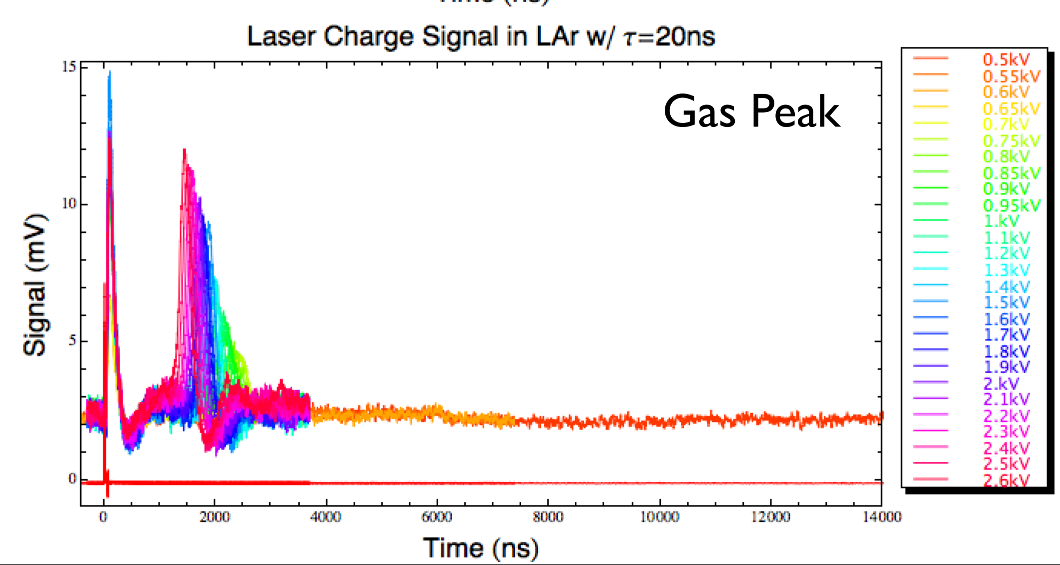



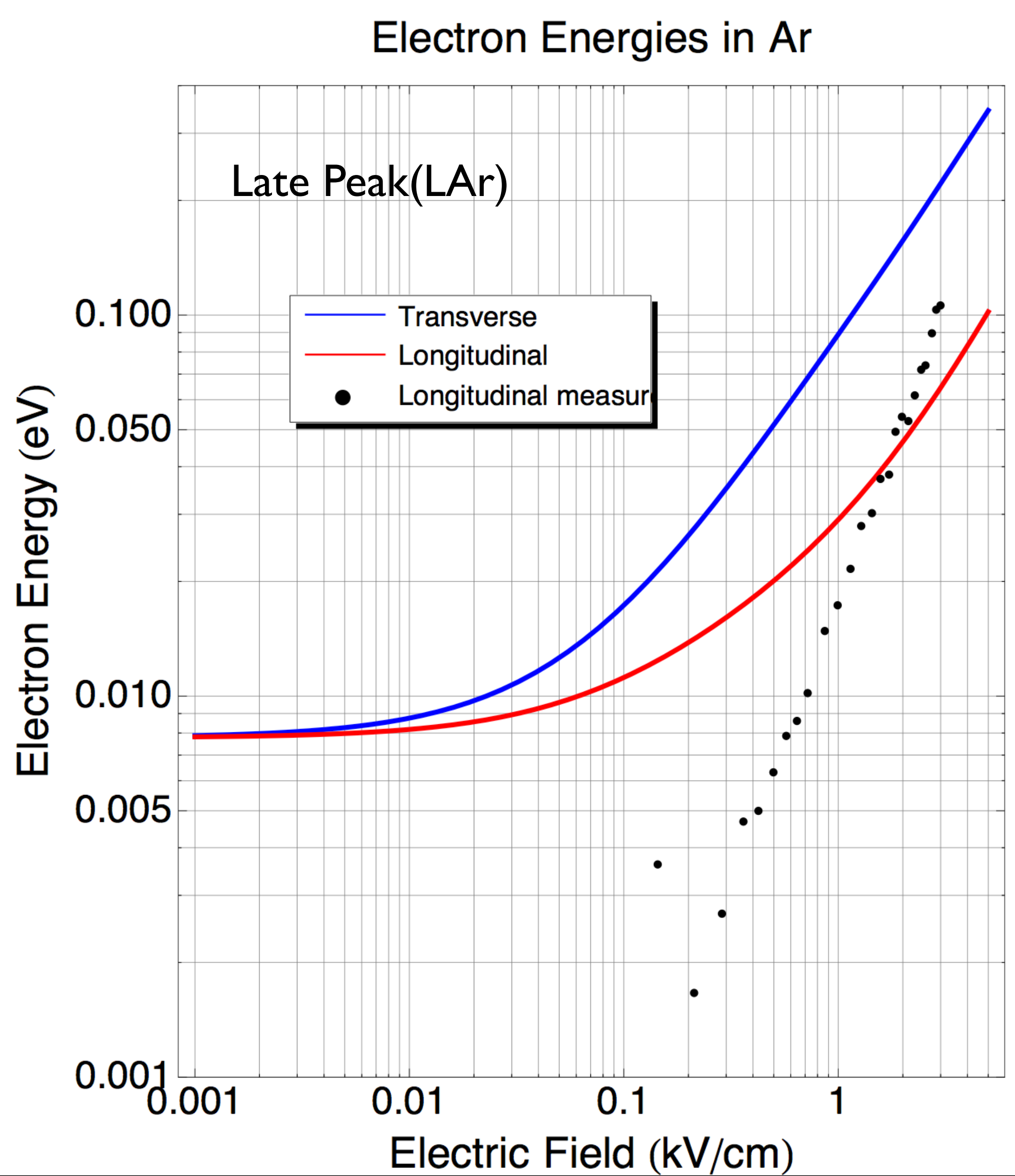



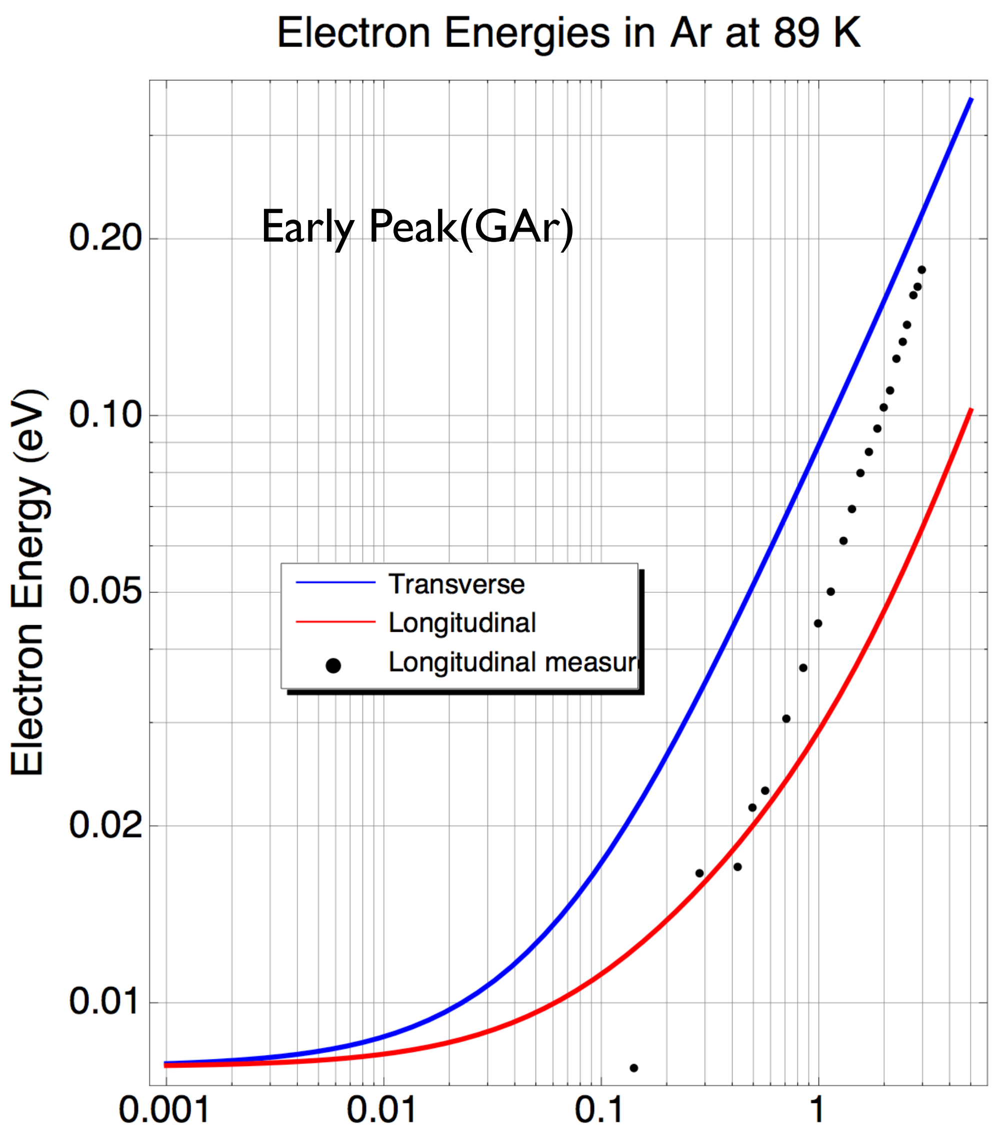
# Electron temperature

1. The electron temperature describes the electron diffusion.

$$\varepsilon_e \equiv \frac{eD_e}{\mu_e}; \quad \sigma = \sqrt{\frac{2\varepsilon_e \Delta z}{E_D}}$$

2. Need to establish longer distance measurements to compare the diffusion.

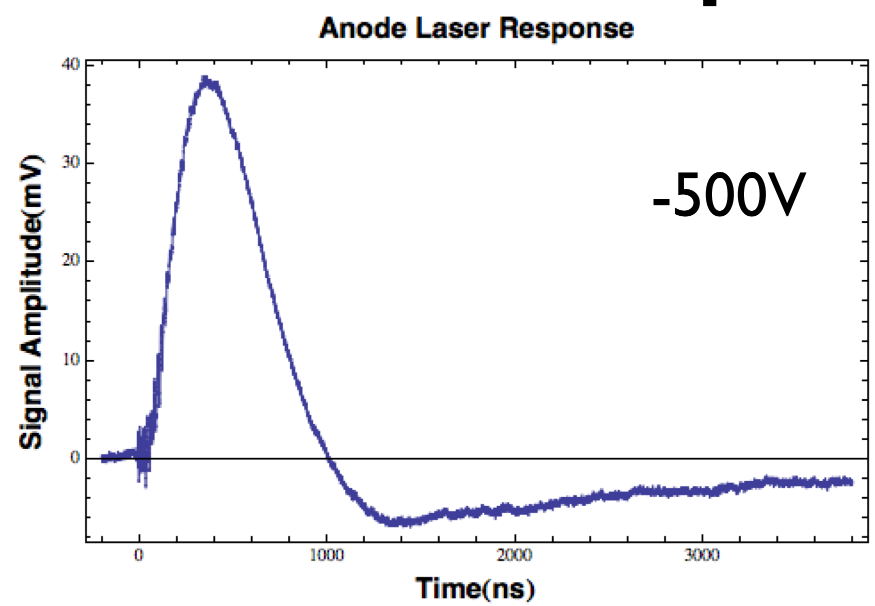


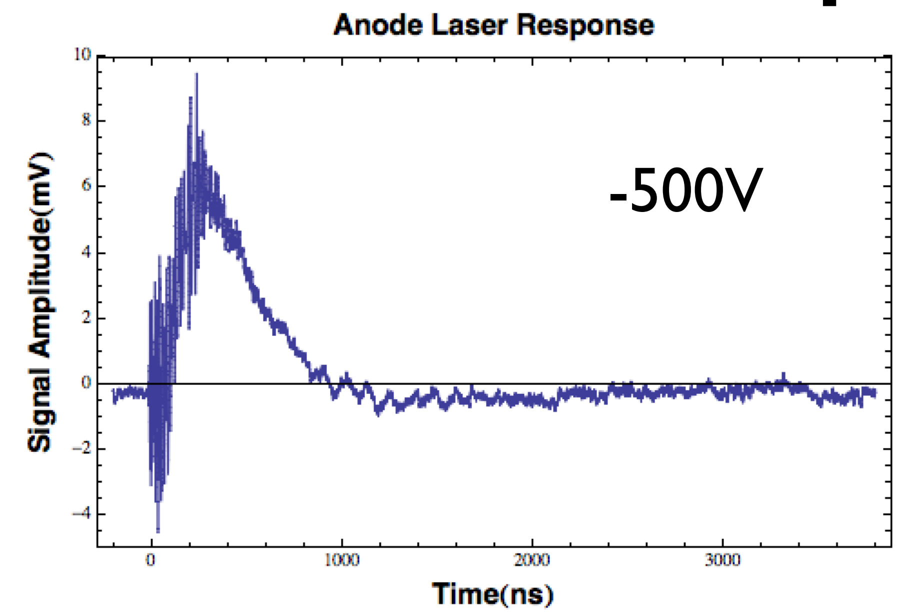
# Anode Laser test Results

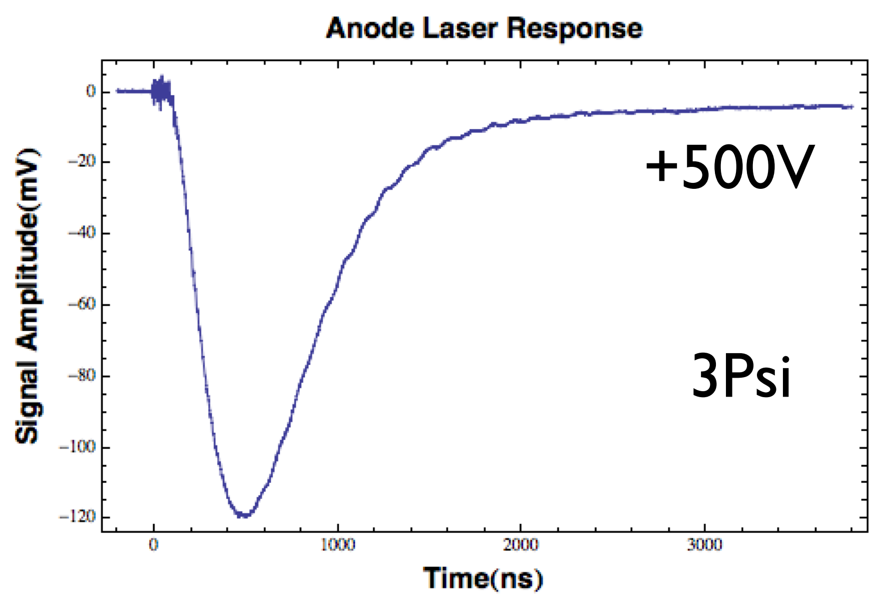
1. Anode was tested with direct laser illumination in air to investigate the mysterious peak.
2. The laser is 15uJ, 10Hz, with shaping time of 200ns, Gain=250.

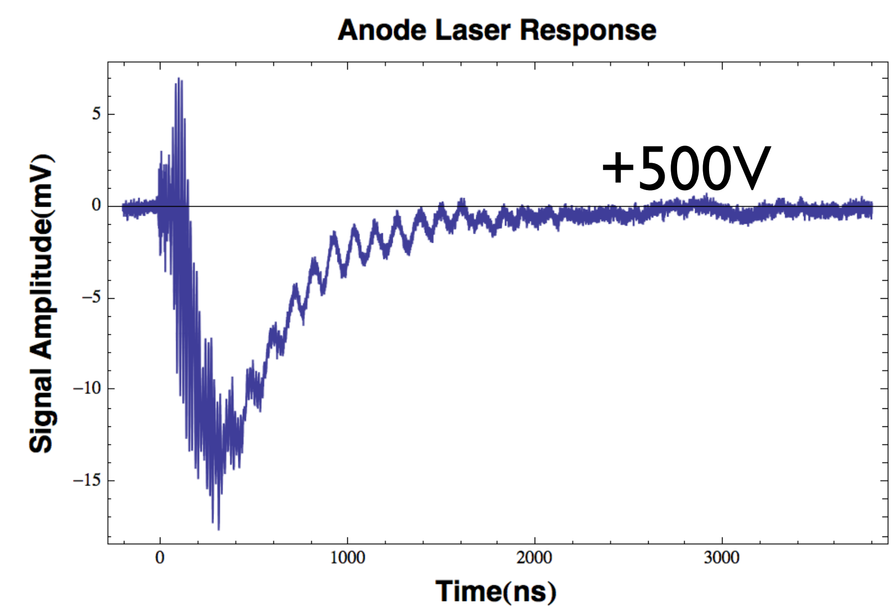
**Our Preamp**

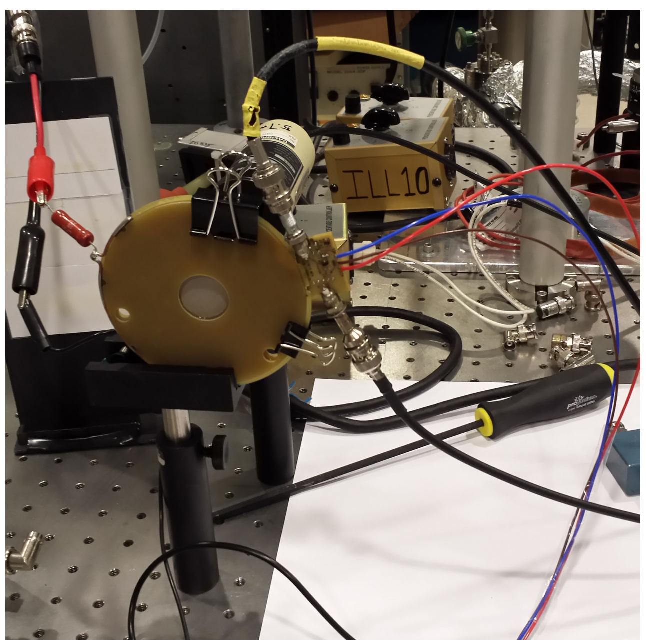


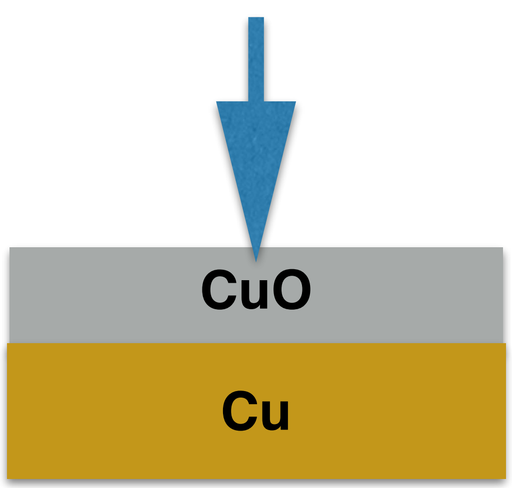

**Thomas' Preamp**

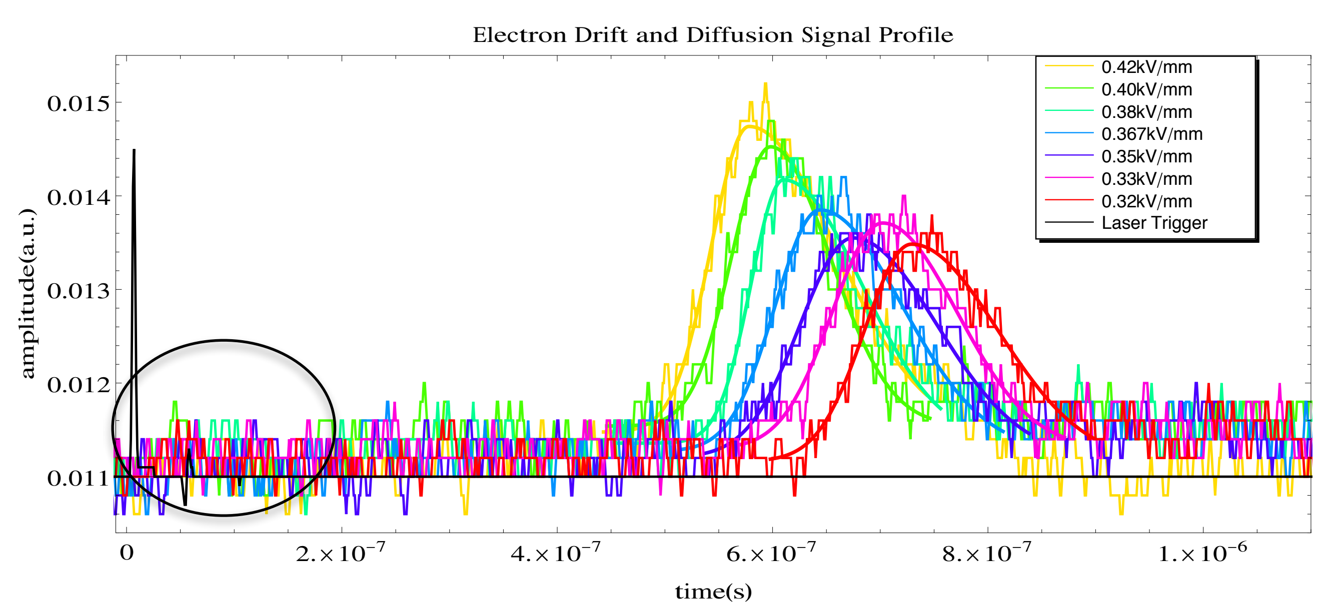


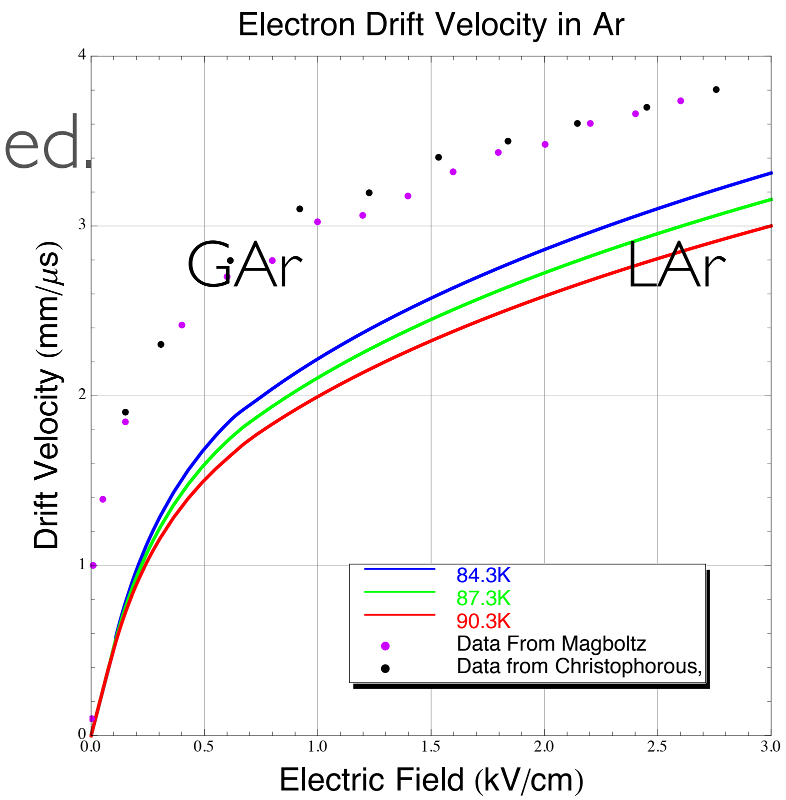





# Electric Field Uniformity Problem

1. Electric Field calculated by Maxwell 2D indicates very nonuniform electric field.
2. The two plots on the left show the calculated field distribution with 0.831kV to 0.831cm HV voltage applied.
3. The electron drift velocity in GAr and LAr are known.
4. The expected drift velocity can be calculated.
5. The influence of field uniformity to the drift velocity is negligible



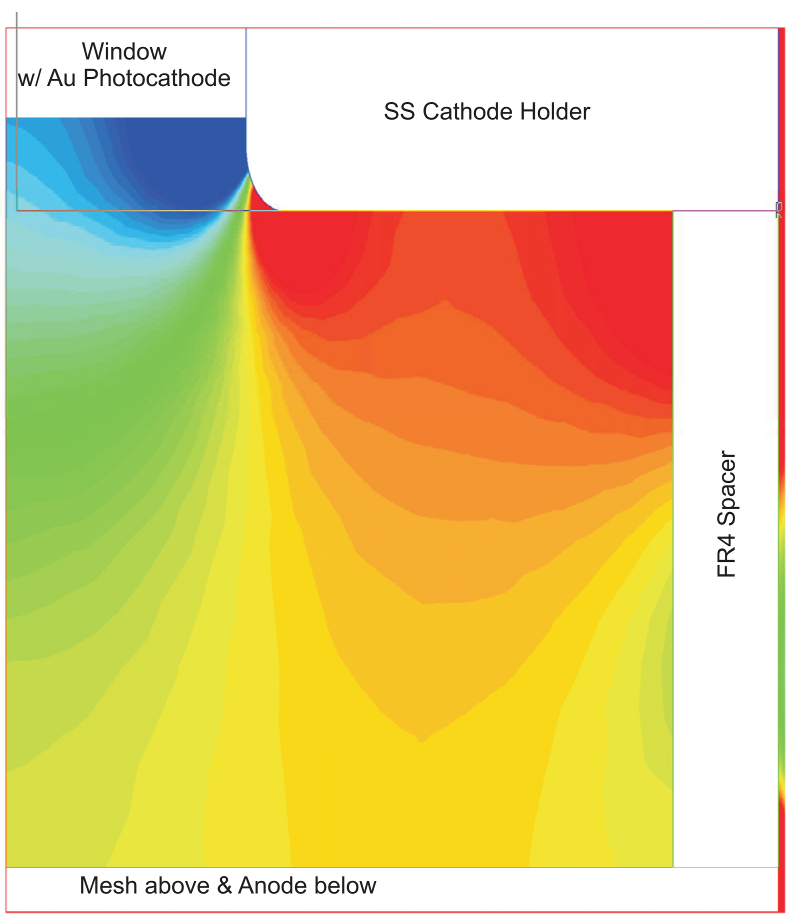

$$t = \int_0^d \frac{dx}{v(E(x))}$$

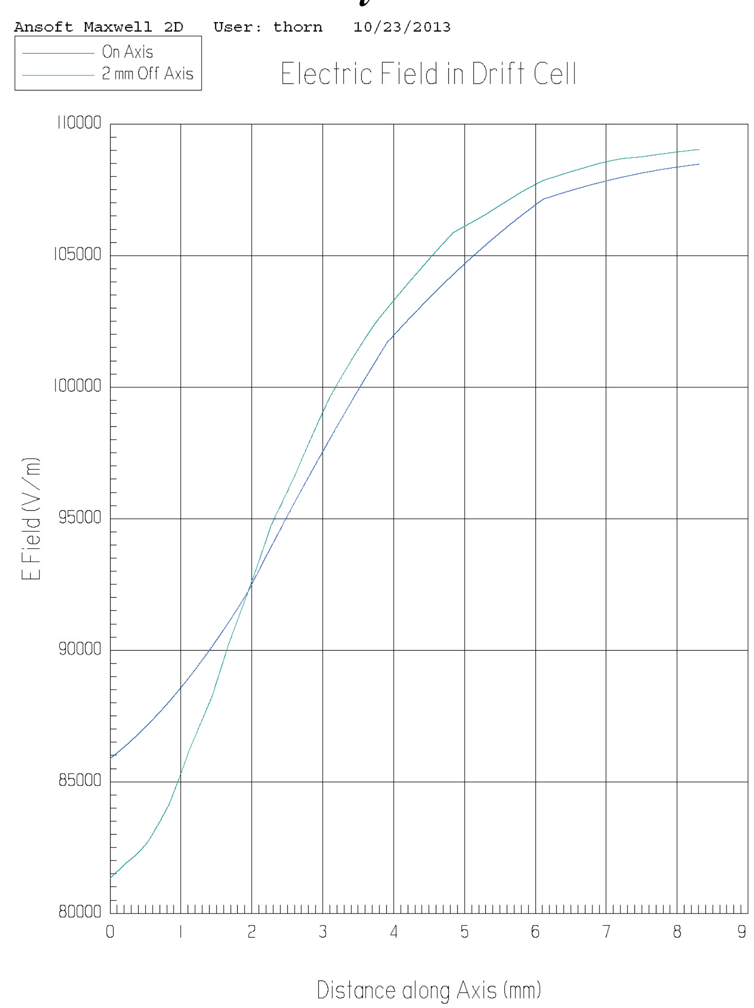
$$\bar{v} = \frac{d}{t}$$

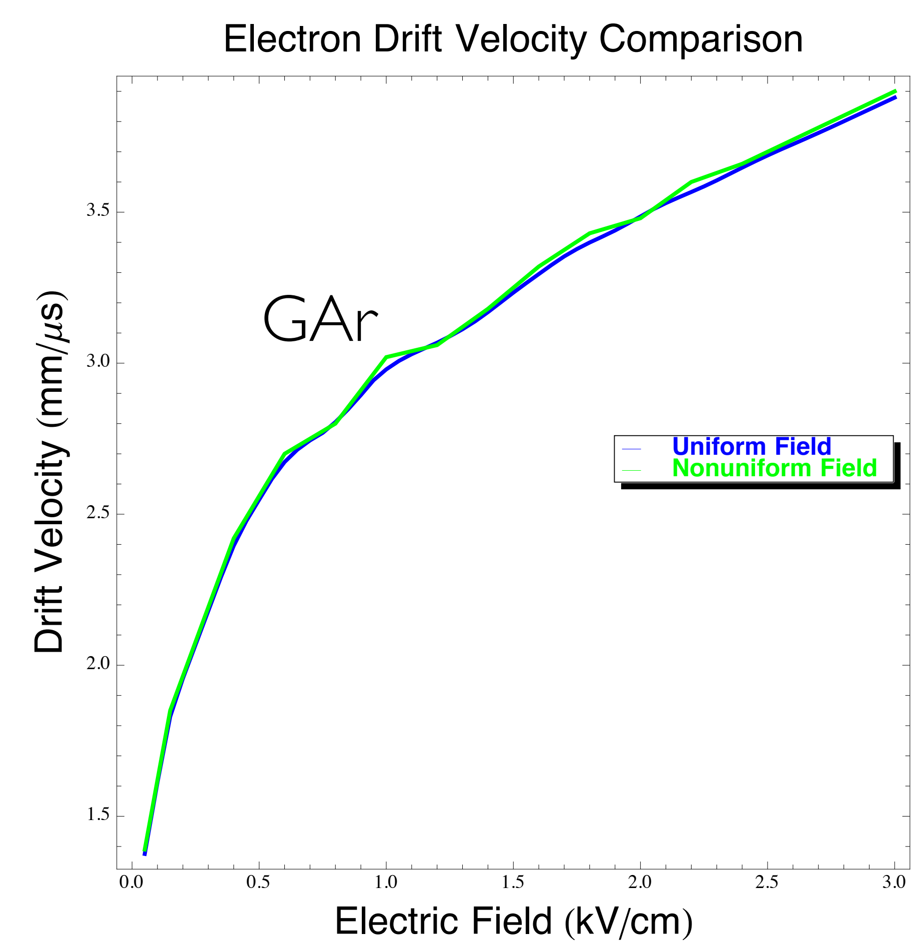
Uniform $\leftrightarrow$ Nonuniform

$$E \leftrightarrow E(x)$$

$$v(E) \leftrightarrow v(E(x))$$

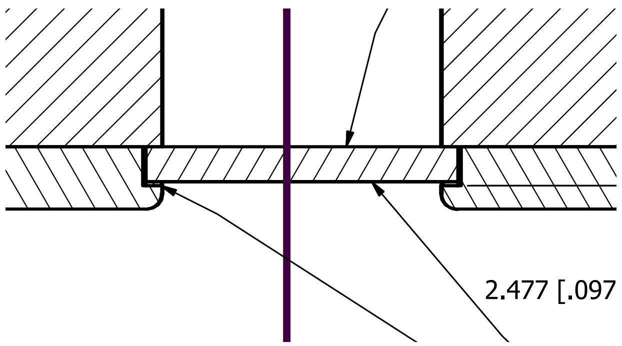


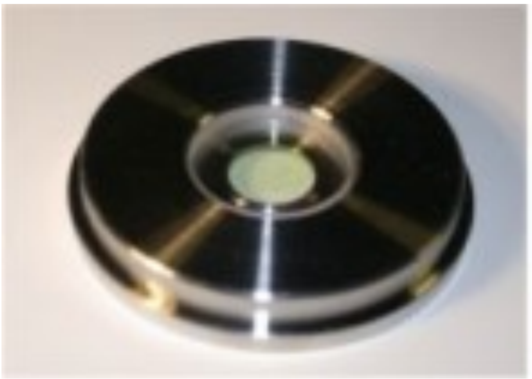
# Electric Field Uniformity Solution

1. The electric uniformity is dominated by the displacement between the photocathode surface and the holder plate.
2. Two solutions are applicable.



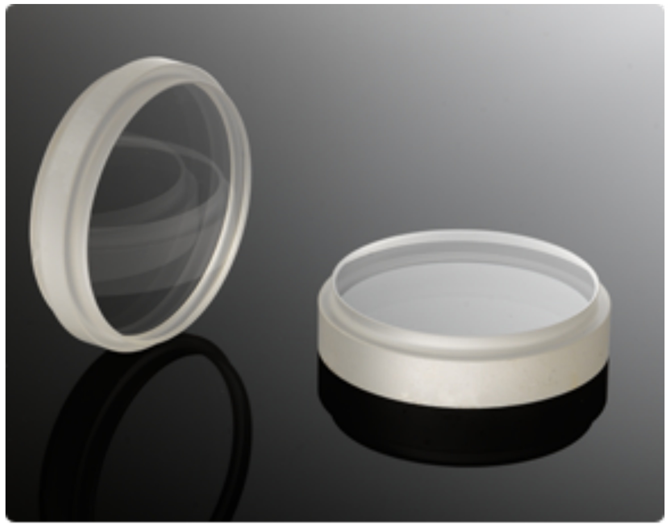

## Solution 1:

1. Flip the holder plate and weld the photocathode to plate.
2. *S-bond technologies* can provide the service with ~1week lead time, cost 1-2k.



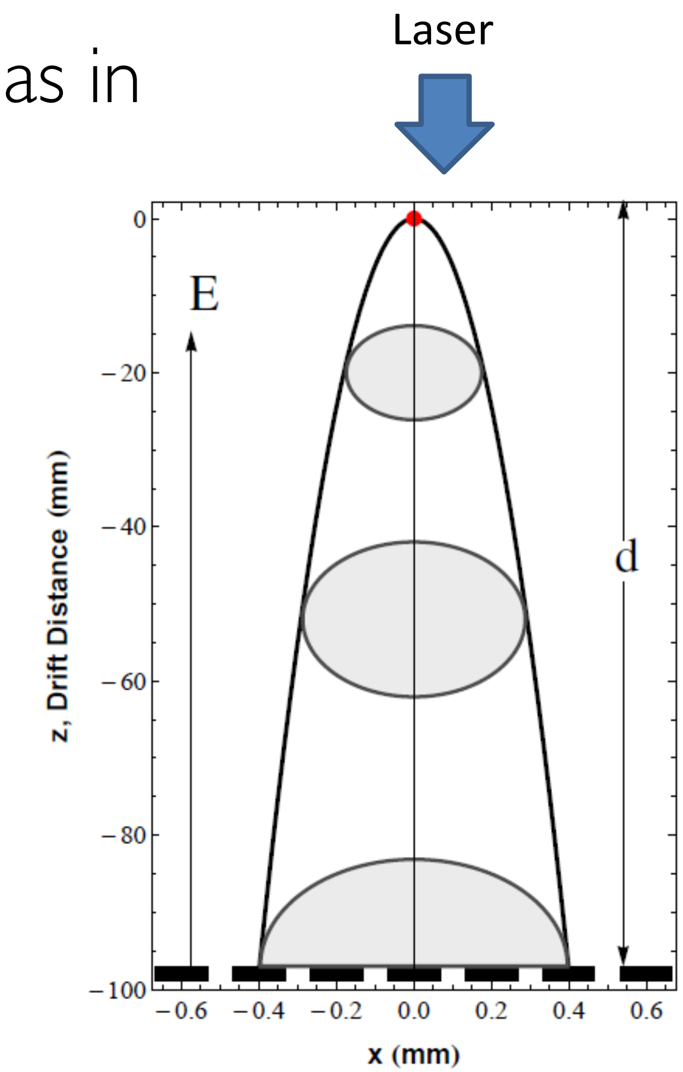
## Solution 2:

1. Using a sapphire substrate with step edge.
2. *Guild Optical Associates LLC* can supply the customized cut sapphire with 4-6weeks lead time, cost for 2-5pics is $1485.



# Transverse Diffusion Measurement

Transverse diffusion will be measured by the similar method as in
**E. Shibamura, *et al.*, Phys. Rev. A20 (1979)**




$$n = \frac{n_0}{4\pi D_T t (4\pi D_L t)^{1/2}} \exp\left[-\frac{x^2+y^2}{4\pi D_T t}\right] \exp\left[-\frac{(z+v_d t)^2}{4\pi D_L t}\right]$$

Can be written as:

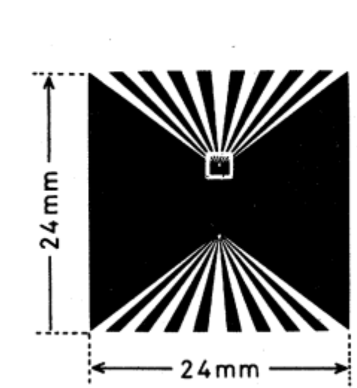
$$n(r) = \frac{n_0}{\pi^{1/2} R^3} \exp\left[-\frac{r^2}{R^2}\right]$$

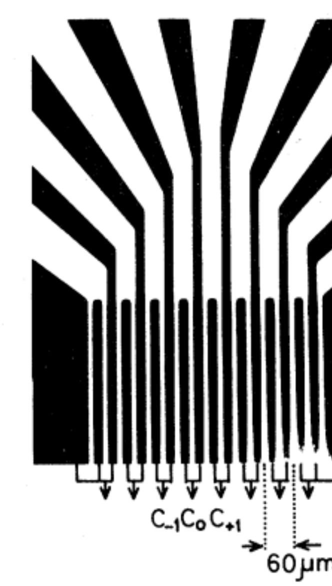
$$r^2 = x^2 + y^2 + (z^2 + v_d t^2) \qquad R^2 = 4 D_T t$$

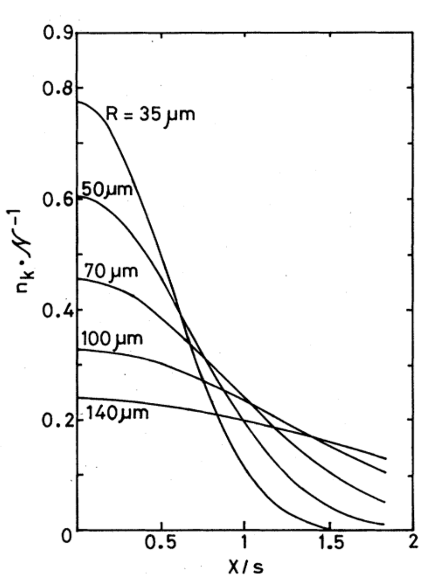
The number of electrons $n_k$ that arrive at the collector $c_k$ can be calculated by integration over each collector.

$$R = \sqrt{4 D_T t}$$

is the transverse radius of the electron swarm




$$\frac{eD_T}{\mu} = e\frac{R^2}{4t}\frac{E}{v_d} = e\frac{R^2 V}{4d^2}$$

*Small spot size of laser is crucial for transverse diffusion measurement

## Conlusions:

1. The minimum electron drift distance measurement are finished.
2. Two more similar measurements with longer drift distance are planned.
3. Some modifications are needed for the future measurements.
4. Transverse diffusion measurements are the next step.

# Signal Shape